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OBSERVATIONS OF A NATURALIST IN THE
PACIFIC BETWEEN 1896 AND 1899





NA RARO (2,420 feet) from the south-west, a peak of acid andesite.



NDRANDRAMEA (1,800 feet) from the south-east, a peak of acid andesite rising about a thousand feet from its base.

[Frontispiece.]

OBSERVATIONS OF A NATURALIST IN THE PACIFIC BETWEEN 1896 AND 1899

BY

H. B. GUPPY, M.B., F.R.S.E.

VOLUME I

VANUA LEVU, FIJI

A description of its leading Physical and Geological characters

London

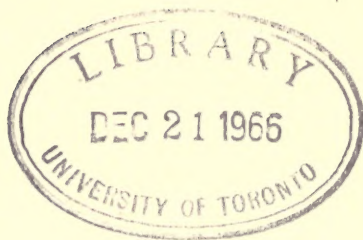
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Dedication

TO THE FIJIAN PEOPLE

PREFACE

DURING a sojourn in the Pacific, which covered a period of rather over a year in Hawaii (1896-97), and of two years and three months in Fiji (1897-99), my attention was mainly confined to the study of plant-distribution and to the examination of the geological structure of Vanua Levu.

With Hillebrand's "Flora of Hawaii" always in my hands I roamed over the large island of Hawaii, ascending the three principal mountains of Mauna Kea, Mauna Loa, and Hualalai, and in the case of my second ascent of Mauna Loa spending twenty-three days alone on its summit. Similarly in Fiji, Seemann's "Flora Vitiensis" was my counsellor and guide in the matter of plants.

In Hawaii I was in a land of active sub-aerial volcanoes, and I paid my devotions at all the altars of "Pele," their presiding deity. In Fiji I trod upon the surface of submarine volcanoes that emerged ages since from the ocean and still retain their coverings of sea-deposits. Both in Hawaii and Fiji I lived much among the people; and though my chief interest lay in the comparison of these two types of volcanic islands, I could not but be drawn to the kindly natives whose hospitality I so long enjoyed.

Destiny led me to Vanua Levu in the following fashion. With the relief party to take me down from Mauna Loa there arrived a well-known German naturalist who, like myself, had been interested in coral-reef investigations. We discussed this warm topic at an elevation of nearly 14,000 feet above the sea, with the thermometer at 20° F. As we sipped our hot coffee and listened to the

occasional "boom" from the bottom of the great crater, at the edge of which we were camped, I remarked to my friend that I was thinking of spending some months in Samoa. To this he good-humouredly replied that I might leave Samoa to his countrymen and describe one of the large islands of Fiji. International rivalry over that group of islands was then rather keen. However, Dr. K. went to Samoa, and I have now completed this volume on the geology of Vanua Levu, Fiji.

It will not be necessary to lay stress here on the difficulties and hardships connected with the exploration of little known tropical regions. Many will be familiar with all that these imply, where the rainfall ranges from 100 to 250 inches, where the forests are dense, where tracks are few and swollen rivers are numerous, and where the torrent's bed presents often the only road.

The only extensive geological collections made in Fiji previous to my visit were those of Kleinschmidt in 1876-78, which together with a small collection previously made by Dr. Gräffe were examined by Dr. A. Wichmann. These rocks were obtained from Viti Levu, Kandavu, Ovalau, etc., but not from Vanua Levu. Dr. Wichmann's paper of 1882, descriptive of these collections, presents us with the results of one of the earliest studies by modern methods of research of the volcanic rocks of the Pacific Islands. It is to this investigator that we are indebted for the establishment of the occurrence of plutonic rocks, such as granites, gabbros, diorites, in Viti Levu.

Although, as far as I can ascertain, few, if any, rocks have been specially described from Vanua Levu, this island was visited by Dana in 1840 when attached to the United States Exploring Expedition under Wilkes. His observations on its geology were published in his volume on the geology of the expedition. Although not extensive they are valuable from their reference to his discovery of trachytic and rhyolitic rocks as well as acid pumice-tuffs in the island. It is singular that his observations have apparently been overlooked by all his successors. Wichmann with this discovery unknown to him remarked on the seeming absence of quartz-bearing recent eruptive rocks from the South Seas.

When the "Challenger" Expedition visited the group in 1875 some geological collections were made which were described by Prof. Renard in the second volume on the "Physics and Chemistry" of the expedition. No collections, however, were made in Vanua Levu. In 1878 Mr. John Horne, Director of the Botanic Gardens at Mauritius, made some important observations on the geological structure of this island and of other parts of the group, which he published in his account of the islands given in "A Year in Fiji." No collections were obtained by him; but prominence is given to his observations by Dr. Wichmann and others. Like Dana in the case of the acid volcanic rocks, Mr. Horne has forestalled me in his conclusion that Vanua Levu amongst the other larger islands has been formed mainly of the products of submarine eruptions.

The visit of Prof. A. Agassiz to Fiji in 1897-98 gave a fresh impetus to its geological investigation. We are indebted to him not only for his own extensive memoir on the islands and coral reefs of this group, but also for the subsequent important explorations of Mr. E. C. Andrews and Mr. B. Sawyer in Viti Levu and the Lau Islands. These two gentlemen have since published a short paper on the caves of these islands. Mr. Eakle has described the volcanic rocks collected during the visit of Prof. Agassiz. It is, however, noteworthy that, although the collections were made in Viti Levu, Kandavu and in many other of the smaller islands, Vanua Levu is not represented. Mr. Eakle's conclusion that basic andesites and basalts are the characteristic rocks of the region, the augite-andesites predominating, would apply to Vanua Levu in great part. This island possesses also in fair amount hypersthene-andesites and dacitic or felsitic andesites, which are very scantily represented in the collections examined by Mr. Eakle. In connection with the quartz-porphyrries and trachytic rocks which also occur in Vanua Levu, it should be observed that Mr. Andrews describes a rhyolite from Suva in Viti Levu. Unlike Viti Levu, Vanua Levu displays but a small development of plutonic rocks.

In conclusion it should be pointed out that much remains to be done in the geological exploration of this island, and that I would have spent a third year in this task much to my profit. Still I

hope that a period of two years devoted to its investigation will be regarded as some excuse for a certain over-confidence in the expression of my opinions.

To enumerate all those from whom I received much kindness in these islands would be a lengthy task. My indebtedness is very great to Bishop Vidal, Father Rougier, and to various other members of the Roman Catholic Mission, and I experienced similar favours at the hands of Mr. Williams and other Wesleyan Missionaries in Vanua Levu. Mr. F. Spence and Mrs. Spence showed me great kindness, and from Dr. Corney I received valuable assistance on my arrival in the group. To the planters my debt is equally great, more especially to Mr. Barratt, Mr. Dods, and Mr. Mills.

In conclusion I would suggest the foundation of a "Fijian Society" for the investigation of the islands, for the gathering together of all that has been written about the group and its people, and for the advancement of science.

HENRY BROUGHAM GUPPY.

June, 1903.

Note.—A type set of my geological collections representing the massive rocks from this island has been kindly accepted by the Curator of the Geological Museum, Jermyn Street.

LIST OF SOME OF THE PRINCIPAL AUTHORITIES QUOTED IN THIS BOOK

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OBSERVATIONS OF A NATURALIST IN THE PACIFIC

CHAPTER I

GENERAL INTRODUCTORY REMARKS ON SOME OF THE LEADING PHYSICAL FEATURES OF THE ISLAND

THE remarkable shape of this island at once attracts the attention : and indeed it is in its irregular outline and in the occurrence over a large portion of its surface of submarine tuffs and agglomerates that will be found a key to the study of its history. With an extreme length of 98 miles, an average breadth of 15 to 20 miles, and a maximum elevation of nearly 3,500 feet, it has an area, estimated at 2,400 square miles, comparable with that of the county of Devon.

Whilst its peculiarly long and narrow dimensions are to be associated with the narrowing of the submarine basaltic platform, from which it rises together with the other large island of Viti Levu, its extremely irregular shape is closely connected with the composite mode of its origin. We have here exemplified the process of the building up of a continental island in the great area of emergence of the Western Pacific, that region which displays at various heights above the sea the ancient reefs and the underlying deposits of the Solomon Islands, New Hebrides, Fiji, Tonga, &c. But this process of construction has never been completed, and is at present suspended ; yet it is in its incomplete condition that Vanua Levu possesses its importance for the investigation of this subject.

This island has in fact been formed by the union of a number of smaller volcanic islands during a long protracted period of emergence. These original islands are indicated approximately by the 1,800-foot contour-level in the accompanying map. There is, however, no reason for supposing that the movement of emergence has altogether ceased. In the course of ages the extensive submarine

plateau, from which it rises, will be laid bare ; and the small surrounding islands that are situated upon it, such as Yanganga, Kia, Mali, Rambi, Kioa, &c., will be included in the area of Vanua Levu.¹

Excluding for the moment the effects of denudation, which have been very great, we shall be able to discern some of the stages of the building-up of the island during the emergence or upheaval by looking at the map and reversing the process in imagination. A subsidence of only 50 feet would cause the Natewa Peninsula to be isolated by a sea-passage along the line of the Salt Lake ; whilst several islands would be formed along the northern and southern coasts, and the Naivaka Peninsula would become detached. If the subsidence extended to 300 feet, the sea would flow over a large portion of the island, where it would regain what was not many ages since its own, an area of basaltic plains, which by their prolongation under the sea form the great submarine plateau. A subsidence of 1,000 feet would break up the remaining elevated axis of the island into a number of lesser portions ; and after a total lowering of 1,800 feet there would exist only a few scattered islands, the arrangement of which would show but little relation to the present form of Vanua Levu. At either end of the area there would arise from the sea the isolated volcanic peaks of Seatura and Ngala (Mount Freeland) ; and between them would be situated four or five long narrow islands, together with a group of small islands and islets where Na Raro and the other acid andesite mountains of the Ndrandramea district now lie.

As might be partly expected, there is in the surface-configuration of the interior of Vanua Levu an absence of that simplicity of contour which exists in a volcanic island of supra-marine formation, as for instance in the large island of Hawaii where the three great volcanic mountains of Mauna Kea, Mauna Loa and Hualalai together with the older Kohala range, determine the form of the whole island's surface.² Here in Vanua Levu there is, on the contrary, but little order amongst its physical features. The rivers often run obliquely with the sea-border, whilst mountains frequently rise at the coast and plains lie far inland, and the view of the elevated interior, as obtained from one of the peaks, presents in many parts a series of mountain-ridges running athwart the island's axis.

¹ In the case of the island of Faro in the Solomon Group, I have described a similar process of island-building. (*Geology of the Solomon Islands*, p. 37.)

² In 1897 I spent several months in travelling over this island and ascended, sometimes more than once, the three great volcanic mountains. Perhaps at some future time I may renew my examination of this interesting region.

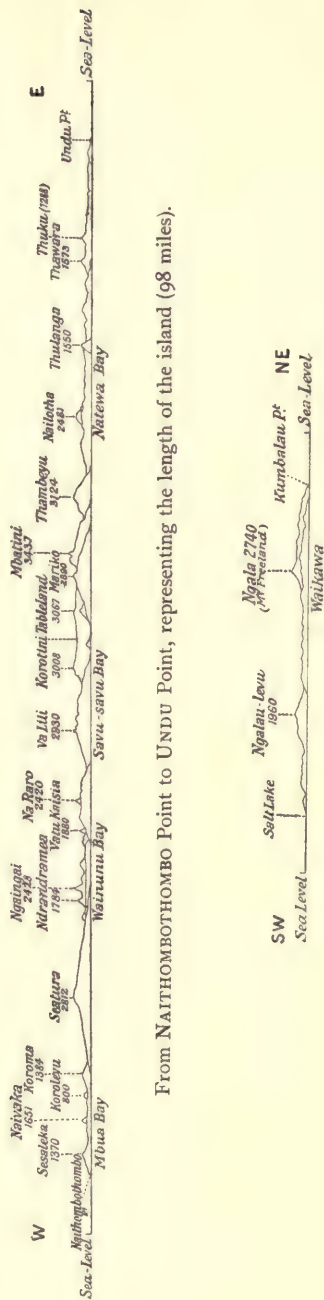
A study of the profile of the island is an important preliminary step to its more detailed examination. One may ramble over a particular region of it for weeks, as I have done, without getting any satisfactory idea of the true configuration of the surface. In a locality densely wooded and occupied by steep mountain ridges and deep gorges, the field of view is often very limited; but seen from the deck of a passing ship the main features of the island assume their true proportions and relations, and much that was uncertain is in this manner made plain. The profile here given has been constructed from a number of others, and represents in a graphic fashion Vanua Levu as viewed from the southward. I have here sacrificed smaller details and occasionally some degree of accuracy in small matters in order to bring out the principal features of the island.

At and near the extreme western extremity rise the conspicuous hills of Sesaleka (1,370 feet), Naivaka (1,651 feet) and Koroma (1,384 feet), all of them formed of basic volcanic materials.¹ Naivaka, which is connected with the main island by a narrow isthmus, only about 30 feet in height, is probably one of the most recent additions to the island's area; and it is at the same time one of the most recent of the numerous volcanic vents that once existed. The leading feature, however, of this end of Vanua Levu is the great mountain of Seatura (2,812 feet), which occupies a large part of the Mbua province and monopolises most of the landscape whilst largely determining the form of the western extremity of the island. It is a basaltic mountain of the Mauna Loa type, its long eastern slope descending gently at an angle of three or four degrees for about ten miles to the mouth of the Wainunu River. In its deeply eroded radial valleys and gorges, and in other respects, it is not unlike the island of Tahiti, as described by Dana.

The Ndrandramea region to the eastward, which I have named after one of its best known peaks, has a profile of a very different character. Its broken outline indicates the existence of numerous mountains and hills of acid andesites, occasionally dacitic. Although some of them attain a height of 2,000 feet and over their tops alone are seen from seaward. Between the foot of these mountains and the south coast extends a great plateau of columnar basalt, incrustated at its borders with submarine deposits, which descends coastward with a very gentle slope, the fall in about five miles being only about 300 feet (1,100 to 800 feet). It terminates abruptly opposite the elevated headland of Ulu-i-ndali, a

¹ Strictly speaking Korolevu indicated in the profile would not be visible.

PROFILES OF VANUA LEVU AS VIEWED FROM THE SOUTH. GRAPHICALLY REPRESENTED ON A HORIZONTAL SCALE OF ABOUT 16 MILES TO THE INCH.



From NAITHOMBOMBO Point to UNDUE Point, representing the length of the island (98 miles).

The NATEWA Peninsula from the Salt Lake to Kumbalau Point.

range, composed mainly of grey olivine-basalts, which is not indicated in the profile.

The two conical peaks of Vatu Kaisia (1,880 feet) and Na Raro (2,420 feet), which rise up so unexpectedly in the region immediately east of the Ndrandramea district, are also of acid andesitic rocks, in the last case approaching the dacitic type. They lie within the borders of the area of basic tuffs, basic agglomerates, and basic massive rocks, that here begins and extends eastward to Mount Thurston and a little beyond. East of Na Raro there is a gap or break in the profile, where the greatest elevation is probably not over 800 feet; and on its farther side rises up the mountain of Va Lili (2,930 feet), a lofty inland ridge that lies towards the southern coast. Palagonite-tuffs and agglomerates are the prevailing surface-formations in this district.

Eastwards from Va Lili extends for eight or nine miles a lofty, level-topped, and almost peakless range, which I have called the Korotini Table-land, after the towns once situated on its southern slopes. Its outline is shown in the background of the view facing page 153. It is, however, not so level-topped as it appears to be; but the gradual variations in elevation between 2,000 and 3,000 feet, when spread over a length of some miles, are more or less lost in the general outline of the range as viewed from the coast. Basic agglomerates are principally exposed on the lower slopes; whilst higher up, reaching often to the summit of the table-land, occur palagonite-tuffs containing tests of foraminifera and molluscan shells, massive basic rocks being exposed in places.

The level profile of the Korotini tableland gives place, as one proceeds eastward, to the broken outline of the several lofty peaks of Mariko (2,890 feet), Mbatini (3,437 feet), Thambeyu (3,124 feet) and others.¹ Each of these peaks marks one of the bold mountain-ridges that form such a striking feature in the surface-configuration of this part of the island. On the slopes of these ridges, and often also on their summits, appear basic agglomerates and palagonitic tuffs and clays often inclosing tests of foraminifera; whilst exposed in the gorges and protruding at times through the tuffs and agglomerates on the crests of the ridges are displayed massive basic rocks of the type of the hypersthene-augite andesites.

East of Thambeyu the level sinks to about 1,000 feet above

¹ Mariko is the native name of the Drayton Peak of the chart. Mbatini is the correct name for the Koro Mbasanga of the chart, the true Koro Mbasanga lying three miles to the north. Thambeyu is a native name for the Mount Thurston Range.

the sea, and beyond rises an irregular group of hills and mountains which attain their greatest height in Nailotha,¹ 2,481 feet above the sea. We are now near the limit of the area of basic rocks. Following the profile as it slopes away, marked by occasional peaks and breaks, towards Undu Point, we pass at first over a district where basic rocks are mixed with those of more acid type ; but before we reach Mount Thuku we enter the district of oligoclase-trachytes, quartz-porphyrries, and rhyolitic tuffs, that extends to the extremity of the Undu promontory.

There remains to be noticed the profile of the Natewa Peninsula. As shown in the diagram, this level begins at a few feet above the sea in the vicinity of the Salt Lake ; and as it proceeds eastward it attains a level of 1,960 feet in Ngalau-levu and of 1,540 feet in the Waikawa promontory, finally culminating, as it nears Kumbulau Point, in a mountainous district which attains its greatest elevation of 2,740 feet above the sea in the lofty ridge of Ngala, the Mount Freeland of the chart. Altered basic rocks prevail in this peninsula ; but more acid andesites also occur, and foraminiferous tuffs and clays are exposed on the slopes, reaching to over 1,000 feet above the sea.

I will conclude this reference to the profile of the island with the remark that if I had neglected to indicate here the close connection that exists between the nature of the surface-configuration and the character of the prevailing rocks I should have ignored a means of investigation which has proved of the greatest value. The rock and surface characters go together. The inland plateau now upheaved 1,000 feet above the sea, was built up by submarine flows of basaltic lava. The isolated conical peak that so unexpectedly intrudes itself into the view is the dacitic core of some submarine volcano long since stripped of most of its fragmental coverings. The lofty mountain-ridges that run athwart the island's breadth, with their summits usually in the rain-clouds received their coverings of tuffs and agglomerates ages ago when they were submerged ; and now they rise to heights of over 3,000 feet above the sea. Bound up with the mysterious origin of these great ridges is the history of the island of Vanua Levu.

These preliminary remarks are only intended to serve as a general introduction to the detailed description of the island and its formations. The closing chapter is devoted to a summary of the principal results of my investigations.

¹ There has been some confusion in the native names of the peaks in this part of the island, which I have not been able to remove.

CHAPTER II.

ON THE EVIDENCE OF EMERGENCE OR OF UPHEAVAL AT THE SEA-BORDERS.

ONE would have expected that in an island where submarine muds and tuffs are of such common occurrence at the surface, extending from the sea-border to elevations of 2,000 feet and over, upraised coral reefs would be also frequent and extensive. But it is remarkable that the uplifted masses of reef-limestone, so characteristic of the islands of the Lau Group, are here very scantily represented. It is certainly true that the fossiliferous volcanic muds that form the foundations of coral reefs are often exposed at and near the coast ; but the elevated reefs that ought to be found reposing on them are rarely to be observed.

It is not to be inferred, however, that in a region so remarkable for the great development of reef-formations coral reefs did not then thrive in these localities, but rather that such a long period has elapsed since the emergence of the present sea-border that the upraised coral reefs at and near the coast have long since been in a great part stripped off by the denuding agencies. Notwithstanding this, it is evident that coral reefs could never have been very extensive at the sea-border during the last stages of the emergence ; whilst they do not appear to have existed at all during the early periods of the history of the island.

In this connection it may be observed that hard compact limestones of any kind are rarely to be found, and only in a scanty fashion. The extensive development of dolomites and hard limestones, described by Mr. Andrews and others in the valley of the Singatoka in Viti Levu, is not a character of Vanua Levu. The foraminiferous and pteropod clays, which exist in the interior and often in the heart of the island, are not overlaid by ancient reef-limestones, but by great masses of volcanic agglomerate and coarse fossiliferous tuffs, the foraminiferous muds in their turn covering the core of massive volcanic rocks. There were no signs

of coral-reef fragments in the volcanic agglomerates in any locality examined, notwithstanding that these agglomerates are so intimately associated with the fossiliferous tuffs and clays that their submarine origin could not be doubted.

The conditions for reef-formation evidently did not exist in that early stage of the island's history, when the foraminiferous tuffs and clays, now occurring at elevations of 2,000 feet and over, were being deposited on the sea-bottom. At some time or other, however, these high mountain-slopes, previous to their emergence from the sea, must have been within the limits of the zone of reef-building corals. If reefs had been formed along those ancient coasts, or on the original shoals, they would have been in some cases preserved, as in the case of the foraminiferous tuffs and clays, by a covering of volcanic agglomerate. These soft submarine deposits have been in this manner saved from the destructive effects of denudation over a large part of the island whether on the higher slopes or at the lower levels; but no trace of reef-formation ever came under my notice in the higher regions of the interior. This is a puzzling point that will have to be considered in connection with the origin of the great mountain ridges, one of the most difficult problems in the history of the building-up of Vanua Levu.

I will now refer to the evidence of the latest stage of the upheaval of the island as indicated at and near the sea-border by the scantily occurring upraised reefs. The elevated reefs are mostly to be found on the south coast between Fawn Harbour and Na Viavia Islet off Harman's or Savu-savu Point. Na Viavia Islet itself is 300 or 400 yards in length and is formed of much honey-combed reef-limestone, which is raised 10 or 12 feet above the high-water line. Proceeding eastward along the south coast of the Savu-savu promontory we next come upon uplifted reefs in a curiously isolated hill that rises on the coast between Naithekoro and Naindi Bay. This hill is about 250 feet in height and is composed in the mass of coral limestone. About 100 feet above the sea-level it exhibits an erosion-line, above which it rises precipitously to the summit. The west point of Naindi Bay is formed of reef-limestone reaching to a height of 40 to 50 feet and displaying in position massive corals, "*Fungia*," and "*Tridacna*" shells. Near its base, four to five feet above the present high-water level, it shows an erosion line. This limestone overlies a rock in which blocks of volcanic rocks, five to six inches across, are imbedded in a calcareous matrix.

Raised coral limestone occurs at intervals on the coast between

Naindi Bay and the mouth of the Salt Lake Passage, usually forming low islets, of which the smaller about 12 feet in height often assume, through the erosion of the sea at their base, that peculiar mushroom-shape, so characteristic of upheaval on reef-bound coasts. The passage into the Salt Lake lies in a slightly elevated reef-mass; and the islet which rises up in its centre to about a foot above the water-level is mainly formed of coral blocks, although I did not find any remains of coral on the low neck of land intervening between the Salt Lake and Natewa Bay. Eastward from the Salt Lake Passage to Nanutha in the vicinity of Fawn Harbour low cliffs of coral limestone, six to eight feet high and occasionally displaying massive corals in position, most frequently constitute the sea-border, rarely, however, extending more than a few paces inland or attaining there a greater elevation than 12 or 15 feet.

This limitation of the upraised reef-belt to the immediate vicinity of the coast is true of all this district. It is only when the sea-border is low and swampy that it is found 100 or 200 yards inland; and in any case as one follows it inland it soon gives place to the fossiliferous mud-rocks and tuffs of the interior. It should be noted that the upraised reefs of this region were rarely observed at greater heights than 20 feet above the sea, in fact usually at a much lower level. The exceptional occurrence in mass of reef-limestone at a height of 250 feet in a coast hill between Naithekoro and Naindi therefore lends colour to the idea that the elevated reefs formerly extended farther inland and that they have been stripped off by denudation.

On the north coast of the Natewa Peninsula elevated reefs are of very rare occurrence. I walked along the whole of that coast from the head of Natewa Bay to within four miles of Kumbulau Point and only found them in the locality, one to one and a half miles west of the mouth of the river Ndreke-ni-wai. Here there were two islets, 20 to 25 feet high and lying close to the shore, which were formed entirely of coral-rock, massive corals occurring in position in their lower part. Although, however, upraised reefs are so scantily to be found on this coast, other proofs of upheaval are to be observed in the fossiliferous tuffs exposed occasionally by the beach. On the east coast of this peninsula, between Ndevo and Loa, submarine tuffs and sandstones, at times fossiliferous, were alone noticed.

Upraised reefs are also very rare on the north coast of Natewa Bay. Here again I traversed the whole coast from the head of the

bay to Undu Point, a distance as the crow flies of about 50 miles ; but I find no record in my notes of any elevated reef-formations. However the calcareous nature of the volcanic tuffs exposed in places at the coast indicate emergence. The extreme rarity, if not the absence, of upraised reefs on this long stretch of coast, which is usually bordered by shore-reefs, is very remarkable, more especially since there is extensive evidence of upheaval in the plains of Kalikoso in the interior, as indicated in the succeeding paragraph.

On the other side of Undu Point, between that headland and Lambasa, elevated reefs did not come under my observation, although in the low-lying inland district of the Kalikoso lake silicified corals are scattered about in quantity at an elevation of 20 or 30 feet above the sea. But the emergence of the sea-border is shown in the occurrence of a "Globigerina" sedimentary tuff near Visongo at a height of 200 feet (see page 221), and by the occasionally calcareous character of the pumice-tuffs that mainly compose the coast cliffs. Near Nukundamu these tuffs of the shore cliffs inclose subangular fragments of massive corals of the size of a walnut ; whilst in a cutting between Mbuthai-sau and Lambasa, about 50 feet above the sea, I observed bits of coral limestone in a basic tuff. Mr. Horne refers to seams or layers of coral limestone occurring in the volcanic agglomerate of the coast cliffs between Lambasa and Tutu Island.¹ Since his experience of this coast was mostly confined to a passage in a canoe along the shore, it is very probable that he only saw the beds of white pumice-tuffs that prevail in places on this coast. I found no beds of coral limestone in the shore-agglomerates of this coast, nor does Dana in his description of the pumiceous formation of the cliffs of Mali Point make any reference to them.²

Along the stretch of 50 miles of coast between Lambasa and Naivaka upraised reefs are of infrequent occurrence. However between Lambasa and Wailevu, coral limestone is extensively exposed in a low range of hills a mile or two inland but not over 100 feet above the sea. No elevated reefs came under my notice between the mouth of the Wailevu river and Nanduri Bay. That a small upheaval has been recently in progress in this part of the coast is indicated by two circumstances. In the first place an erosion-line about a couple of feet³ above the high-water line, and

¹ *A Year in Fiji*, 1881, pp. 22, 167.

² *Geology of the United States Exploring Expedition*, 1849.

³ This height has been supplied from memory, as I omitted to refer to the exact level of the erosion line in my notes.

a few paces removed from it, is displayed in the volcanic tuff of the point bordering the reef-flat on the east side of Nanduri Bay. In the next place there exist at different places in the midst of the mangrove-belt extensive bare mud-flats, sometimes several hundred yards across, which are only covered by the higher tides. These flats are quite bare of mangrove or any other vegetation and are often cracked on the surface and sun-dried and firm to walk upon.¹ These naked mud-flats in the midst of the mangrove tracts are peculiar to this part of the coast. Their general level must be between one and two feet above that of the mangrove belt in other parts of the island; and I infer that a slight upheaval or emergence has led to the death of the mangroves in these situations.

I know little of the coast between Nanduri Bay and the mouth of the Ndreketi River. At two localities where I landed no elevated reef-formation was observed. Dana referring to the coast opposite Mathuata Island alludes only to the volcanic agglomerates. The low mangrove-bordered coast between the mouths of the Ndreketi and Lekutu rivers was not actually visited by me; but I traversed the region behind the broad mangrove-belt, and found occasionally in the tuffs and muds exposed in the river-banks marine-shells and foraminiferous tests, indicating an elevation of a few feet. I examined much of the coast between Lekutu and the extremity of the Naivaka peninsula, but came upon no upraised reef-rocks. In the low isthmus, 20 to 30 feet high, which connects this peninsula with the main island only volcanic rocks came under my notice. A palagonitic tufaceous sandstone exposed in the cliffs on the north coast of Naivaka contains a little carbonate of lime, and being probably a submarine deposit it implies an emergence of the sea-border.

Although I have been able to produce but scanty evidence of uplifted reefs on the north coast of Vanua Levu, it is probable, judging from the heights given in the Admiralty Sailing Directions, that such formations exist in a few of the numerous low islands and islets that front this coast. Some of these islands and islets, which are often not much more than reef-patches largely reclaimed by the mangroves, will be noticed below when considering the question of the extension of the mangrove belts since the survey of Commodore Wilkes in 1840.

Neither on the south coast of the peninsula of Naivaka nor on

¹ They were described to me as dry for a fortnight at a time. I was prevented from making more than an occasional visit to them.

the west coast of the Sesaleka promontory did upraised reefs come under my observation ; but my acquaintance with the last locality is very scanty. The emergence of the Sesaleka promontory is however indicated by the occurrence inland at heights of at least 700 feet of palagonitic tuffs, occasionally containing foraminifera.

With the long tract of coast between Naithombothombo Point and Solevu Bay, I am fairly well acquainted. However, with the doubtful exception of Lekumbi Point, no elevated reef-formations were observed. Evidence of an emergence of a few feet, and of a very extensive seaward advance of the land-surface in recent times, is afforded by a curious bed of marine shells exposed in the banks of the Mbua River, nearly two miles inland and in the vicinity of the Wesleyan Mission station. This is described on page 58. The submergence at some period of the watershed between the Mbua and Lekutu districts is indicated by the presence of microscopic foraminifera in the hyalomelan tuffs that are exposed in the dividing ridge.

Along the whole coast between the mouth of the Mbua River and Solevu Bay, there are but few if any traces of upheaval. Even volcanic tuffs are of rare occurrence, and there is only the case of the formation of Lekumbi Point to be here referred to. This singular low cape is described on page 60. Here it is sufficient to remark that it is monopolised by the mangroves except at the outer part where the swampy ground passes into the dry sandy soil of a reef-islet, occupied by the usual littoral vegetation, and raised only a foot or two above the high-water level. It exhibits on the beach the bedded sand-rock so often found on coral islets, but this in itself is no evidence of emergence.

Neither on the shores of Wainunu Bay nor in the Kumbulau peninsula were upraised reefs observed, although the presence in places of submarine tuffs inland and near the coast affords evidence of elevation. The same remark applies to the coasts of Savu-savu Bay.

I have little doubt that the absence of elevated reefs on the coasts of by far the greater part of the island is the result largely of denudation. In this case we have to explain why an island in a region of coral reefs exhibits on the surface of its interior submarine tuffs and clays in most localities, whilst uplifted reefs are very rarely to be found at the coast or in fact anywhere. This view receives support from the existence of traces of old elevated reefs in different parts of the island. These traces are afforded by the occurrence on the surface in different localities of silicified

fragments of coral associated with concretions of chalcedony, bits of flints and hornstones, jasper, impure siliceous nodules, &c. The localities may be at the coast or a mile or two inland, and are not usually more than 100 or 200 feet above the sea. This subject is treated with some detail in Chapter XXV. Here I may say that such localities are confined mostly to the open, low, undulating districts on the north side of the island. Silicified corals are not always present with the fragments of chalcedony and other siliceous concretions that are found so frequently in these situations; but from their association in the plains of Kalikoso, where the silicification of corals may almost be observed in operation, the previous existence of corals may be more than suspected in localities where only the other siliceous materials are observed.

I pass on now to some general considerations regarding the relations of the mangrove-belt to the sea-border and the character of the slope of the land-surface as compared with that of the submarine platform. An accurate conception respecting these matters will help one to avoid some pitfalls in forming an estimate of the character of the movement of emergence which this region has experienced.

Beginning with the mangrove-belt, some curious preliminary reflections arise, when we endeavour to look back into the past stages of the history of a mangrove tract in an area of emergence. We might perhaps expect to find the remains of such a belt in the upraised sea-borders; or if no traces existed, we ought to find in some places an extension inland of the reef-flat on which the mangroves at one time flourished. If a rapid movement of emergence is now in progress, the mangroves ought to cover the whole or greater part of the reef-flat; and in the mangrove tract of an emerging area we might look for signs of central decay and marginal growth, the mangroves dying in the middle of the tract and flourishing at the advancing margins.

When, however, we look at the mangrove-belt, as it at present exists around much of the coast of this island, we find that, except in the vicinity of the mouths of rivers, there extends beyond it a considerable extent of bare reef-flat, varying usually between 200 and 1,000 yards in width, and covered by the rising tide. There is no evidence of recent emergence in this condition of things. This relation between the mangrove-belt and the reef-flat indicates a state of equilibrium which might have been established long ago. It is the normal relation that exists between reef and mangrove growth; and it excludes all but very gradual movements of

upheaval or emergence of the sea-border. It is not always easy to see why there should be this fine adjustment between the rapidly-growing mangrove and the slowly-growing reef. Under normal conditions, however, that is to say, when the land is stationary or when the change of level is of a very gradual nature, the reclaiming agency of the mangrove receives a check, and this relation between the mangrove-belt and the outer reef-flat is maintained.

Actual acquaintance with such localities soon forced me to the conclusion that whilst a gradual emergence or upheaval of 3 or 4 feet in a century would not materially affect the relation between the mangrove-belt and the reef-flat, a sudden or rapid change of level of that amount would destroy the mangroves around the whole island. There is some evidence, however, of there having been a rapid upheaval of this kind in different parts of the coast: and it follows, therefore, if this movement was general, that the present mangrove-belts date only from the last upheaval. But this elevation may have occurred ages ago; and the equilibrium between mangrove-belt and reef-flat may have been long since established. Accordingly, the breadth of the mangrove-belt can afford no indication of the period that has since elapsed. From data referred to below, it is evident that the mangrove-belt, taking its average width, away from the estuaries, at about 500 yards, might have been formed in two or three centuries, whilst a thousand years or more may have passed since it assumed its present relation to the reef-flat. If, therefore, upheaval is in progress, it must be of a very gradual character, since the normal relation of mangrove-belt to reef-flat now prevails.

There are indeed signs of such a gradual movement of emergence or of elevation being in operation on the north coast of Vanua Levu at the present time. I have before referred (page 11) to the extensive bare mud-flats in the midst of the mangrove-belt between Nanduri and Lambasa, which are well represented on the Tambia coast and in Nanduri Bay. They are only covered by the higher tides, and in the intervals their surfaces are dried and cracked by exposure to the sun. Here we have the central decay and the marginal growth which would be expected in a mangrove tract situated in a gradually rising area.

An indirect indication of such a slow upheaval on the north coast is to be found in the circumstance that the great submarine platform, which reaches seaward to the line of barrier-reefs, 15 to 20 miles away, passes gradually, as it extends landward, into the

low-lying plains that constitute the sea-border between Lekutu and Ravi-ravi Point. As shown in the profile-section on p. 62, these low coast districts are prolonged inland, with an average rise of between 20 and 30 feet in a mile, to the heart of the island; and we have here an extension inland of the slope of the submarine platform. These broad inland plains, and I may here include those behind Lambasa, are covered over much of their surface with submarine tuffs and clays in such a manner that we may almost trace their continuity at the coast with similar deposits now in actual formation beyond the low-water level on the surface of the submarine platform.

A glance at the map of the island, where these inland plains are indicated by the 300 feet of the contour-line, will make this point more clear. These plains are traversed by the Sarawanga, Ndreketi, Wailevu, and Lambasa rivers; and so slight is the fall that cutters usually ascend the rivers for several miles, whilst the tide extends for a considerable distance up their courses. That the emergence of the inland plains of Kalikoso in the eastern part of the island is comparatively recent there can be but little doubt. In that locality as described on page 224, the low marshy land, surrounding the fresh-water lake of Vakalalatha, although five miles inland, is only elevated 20 to 30 feet or less above the sea, and silicified corals are scattered over its surface.

There is one other method of ascertaining the character and amount of elevation that may be still in progress in this island namely the comparison of the results of surveys of the coasts at different periods. In this manner data may be obtained as regards the growth of the mangrove belt, changes in size of the low reef-islets and islands, and alterations in depth. For this purpose I have employed the charts of the north and west coasts of the island made by Commodore Wilkes in 1840¹ and the Admiralty charts 379 and 382 as completed from the survey of these coasts by Commander Combe in 1895-96.

It was not easy to make many good comparisons in the case of the advance of the mangrove-belt of the main coast. There certainly has been no great advance seaward of the margin of the mangroves in this half century. The average amount probably lies between the estimate obtained for the coast opposite Mathuata Island, where there has either been no change or an advance of only 100 yards or so, and that for the advance seaward of the

¹ *Atlas of the United States Exploring Expedition*, vol. i., Philadelphia, 1850.

mangrove promontory of Lekutu which amounts to 500 or 600 yards. In this last case, however, much of the extension may be due to the advance of the mangroves on the mud brought down by the Lekutu river, so that, as far as these data show, the average advance of the belt of mangroves on this coast between 1840 and 1895 would appear to be slight.¹

On the other hand, the mangrove-borders of the several low islands and islets, mainly formed of reef-*débris*, that lie off the coast, have often extended themselves during this period in a marked degree. The results of my comparisons are given below, the rate of advance being obtained by halving the increase in length or breadth as measured between the mangrove-borders, the breadth being used in the long islands.

Advance of the Mangrove-Borders of Low Islands on the North Coast of Vanua Levu between 1840 and 1895.

Thukini, or Gibson Island of Wilkes . . .	700 to 800 yards
Nangano, or Piner's Island of Wilkes . .	300 to 400 „
Nandongo, or Nuvera of Wilkes	500 „
Talailau (two new islands)	400 to 900 „
Nukunuku or Clark's Island of Wilkes . }	Not much change.
Thakavi, or Day's Island of Wilkes . . }	

It will be noticed that the islands of the Talailau Reef are not marked in the chart of 1840 ; they are both low mangrove islands, the largest being slightly under a mile long and the smallest a little under half a mile. In Nukaira Island, the Vatou of Wilkes, there has been a decrease of about two-thirds of a mile during

¹ This, however, is not the case with the recent changes at the mouth of the Rewa River in Viti Levu, where the bare sandy point of Lauthala has extended itself seaward between 500 and 600 yards since 1840, whilst Port Nukulau has shoaled a fathom in the same period. But I can find no evidence of any marked advance in the mangrove margins either towards Nukulau or on the Kamba side, the only change recognisable being in the bare *sandy* point of Lauthala, the rapid extension of which has been such as to attract the attention of residents, both whites and natives. Dana, who was in this locality in 1840, remarks in the *Geology of the U.S. Exploring Expedition*, that he had learned from a person who had resided there for forty years that during this period the deposits had lengthened the river half a mile. When I was on the Rewa in 1897 I heard that the natives in old time could see Suva Point from Rewa. This is probably a native legend connected with the modern extension of Lauthala Point. (The charts compared in making the above measurement of the recent advance of this point were the plan of the Rewa Roads by Wilkes, in 1840, and the Admiralty charts 1757 and 905, the former of which was based on Lieut. Dawson's survey in 1875, the last being corrected to 1897.)

this period. The difference between Thukini in 1840' and in 1895 is very noticeable. In the time of Wilkes the mangroves only occupied about one-third of the reef-patch. Now they occupy about two-thirds, the area of the reef-patch remaining much about the same. Taking the minus and plus values of all the islands here measured, the average rate of the advance of the mangrove-margins during this half-century may be placed at about 250 yards in the case of these reef-islands, which would amount to a mile in 200 years.

It is probable that a long island like Ndongo, which is about four miles in length, has been formed by the union of smaller mangrove islands. Therefore, taking half its maximum breadth of a mile as a guide, it would at this average rate of growth require two centuries for its formation. But since the extension of the mangroves depends on the growth of the reef-patch, which takes place on the average at a much slower rate, it follows that this can only be a minimum limit for the age of this island. We can only assume that if the reef-patch had suddenly appeared 200 years ago, Ndongo Island could by this time have acquired its present dimensions. It does not follow that the mangrove border has been continuously advancing. A hundred years ago there may have been a state of equilibrium between the growth of the mangrove and the reef-patch, which does not now exist. All we can say of some of these low islands is that the mangroves have been rapidly extending their margins during the last half century, and that the normal adjustment between reef-growth and mangrove-growth, which must have once existed, does not now prevail.

There is evidence of the shoaling of the ship channel amongst these islands to the extent of about a fathom during this period.¹ The usual depth immediately around the patches, on which the islands have been formed, is 8 to 10 fathoms. If, therefore, the shoaling is a general process, it is to be inferred that although the outward growth of the reef-patches would be usually very slow, probably not over fifty yards in a century, there must be times when, in shallowing depths, the growth of the reef-patch would be comparatively rapid; and it is at such times that the adjustment between the relations of mangrove and reef-patch would be upset.

Between Mathuata Island and the coast a change is indicated from 9—10 fathoms to 8—9 fathoms, north of Motua Island 12—13 to 11—12, and between Nungano and Thakavi 16 to 14 fathoms.

so that the advance of the mangroves would be for a time unrestricted.

It is, therefore, apparent that the rate of growth of one of these low islands is not to be determined by the rate of growth of the mangrove-tract occupying the surface. The subject is a complicated one; but I think enough has been said to show that the destructive agencies do not prevail on this great submarine platform on the north coast of Vanua Levu.

If the data here adduced of the increase of the low islands, of the shoaling of the channels, and of the advance of the delta of the Lekutu river,¹ are well founded, all the islands, islets, and reef-patches that lie along this north coast will be united to each other and to the main island within a thousand years.

The facts here produced do not directly indicate a movement of upheaval but they are quite consistent with the conclusion that the great movement of elevation which has built up Vanua Levu by the union of several smaller islands is still in operation at its coasts. To assume that there is now in progress at the sea-border the same process of island-building which has produced Vanua Levu, as we now see it, is to assume a uniformity in nature's methods which is disregarded by the hypothesis that the great submarine platform, from which the large islands of Viti Levu and Vanua Levu now arise, represents the work of marine erosion into the flanks of the upheaved islands since the last elevation. The origin of this submarine platform is dealt with in Chapter XXVII. Here it may be remarked that I regard it as older than the islands that rise from it.

However, this movement of upheaval is so gradual that the utmost one can expect to do by the comparison of surveys made half a century apart is to show the lack of evidence of the destructive agency of erosion. As far as the comparison admits of judging, there seems to have been no important change on the coasts of the western end of the island during this period. The low neck of land connecting Naivaka with the main island, if we take the low-water line in the Admiralty chart as the limit, had much the same breadth at the time of both surveys. The depths in Mbua Bay remain about the same, with perhaps a shoaling of less than a fathom in places. There are two cays awash in the

¹ By referring to the chart it will be seen that extensive mud-flats occur at the mouths of the Sarawanga and Ndreketi rivers, where the land-margin is slowly advancing.

Admiralty plan of this bay which were described as sand-spits in the time of Wilkes. The promontory of Lekumbi could scarcely have been expected to show any extension during this time, since there are depths of 10 to 16 fathoms close to its extremity; and there is in fact no difference of critical importance indicated in the charts.

Some of the principal points of this chapter may be thus summed up:—

(1) Upraised reef-limestones are of very limited occurrence. They occur at and near the coast and do not extend higher than 300 feet. Their scarcity at the sea-border is to be attributed to the denuding agencies.

(2) Since foraminiferous muds and sedimentary tuffs with marine organic remains occur at all elevations up to over 2000 feet, it is assumed that the absence of reef-limestones in the elevated interior indicates the paucity or absence of reef-growths in the early stages of the history of the island. The overlying agglomerates have often preserved from destruction the soft sedimentary deposits beneath; but they seem to have never covered over a coral reef.

(3) The relation between the mangrove-belt and the reef-flat indicates a state of equilibrium which might have been established long ago. If the movement of emergence is still in progress, it must therefore be of a very gradual nature, since the normal relation between the mangrove-belt and reef-flat now prevails.

(4) From the circumstance that the submarine platform passes with a uniform slope into the low-lying plains, covered with submarine deposits, it may be inferred that a very gradual emergence is now in operation.

(5) A comparison of the charts of Wilkes and of the British Admiralty shows that on the north coast of the island during the last half century the destructive agencies of marine erosion have not prevailed.

(6) The results of the comparison of the charts, whilst they do not directly imply a change of level, are quite consistent with the conclusion that the movement of emergence, which has been in operation probably since the later Tertiary period, is not suspended.

Note.—The extensive evidence of emergence presented by this island is treated in Chapter XXVII. in connection with the whole

group. It is not always possible to avoid in such a discussion the use of terms such as "upheaval" and "subsidence," although there is much to be said for the terms "negative" and "positive" employed by Suess. In the present chapter, however, I have avoided committing myself definitely to any view relating to the stability either of the land or of the sea, reserving the consideration of the subject for Chapter XXVII.

CHAPTER III

THE HOT SPRINGS OF VANUA LEVU

THE abundance of hot springs in Vanua Levu, and in fact in the group generally, is not commonly known. In the earlier accounts of these islands those of Savu-savu are often alone referred to, not only for this island but for the whole archipelago. The United States Exploring Expedition under Wilkes spent six months in 1840 in making a survey of the whole group. Yet Dana, who was attached to the expedition, remarks that "the only trace of actual volcanic heat which the islands appear to contain is found at Savu-savu Bay."¹ Horne in his excellent account of the group, which he visited in 1878, was among the first to direct attention to the abundance of hot springs there; but he does not enumerate many. Although he travelled extensively over Vanua Levu, he refers to only three in that island, namely, at Savu-savu, Wainunu, and Wunisawana.² It will be shown below that most of the thermal springs discovered by me might easily have been overlooked.

Before dealing with those of Vanua Levu I will mention the other localities in the group in which thermal springs are from various sources known to me. They probably form but a small proportion of those that actually exist; but the list can be readily extended by those acquainted with special parts of the archipelago. In Viti Levu they occur amongst other places at Wai Mbasanga, on the Singatoka river (Horne) and at Na Seivau on the Wai Ndina, where Macdonald in 1856 found temperatures of 106° and 140° Fahr. in two different springs.³ Mr. Thiele in more recent years referred by hearsay to some hot springs on the Wai Ndina.⁴

¹ *United States Exploring Expedition*, vol. x.; *Geology*, by J. D. Dana, p. 343.

² *A Year in Fiji*, by John Horne, London, 1881, p. 163.

³ *Journal, Royal Geographical Society*, 1857, vol. 27.

⁴ *Scottish Geographical Magazine*, August, 1891.

Kleinschmidt in 1876 visited a hot spring near the village of Nambualu in the island of Ono which rose up in the midst of a brook and had a temperature of about 100° Fahr.¹ The same naturalist in July of that year, when accompanied by Dr. Max Büchner, came upon a hot spring issuing among the mangroves at the coast about a mile from the village of Ndavingele in Kandavu. He did not take the temperature; but he says that Colonel Smythe (about 1860) observed the temperature to be 144° Fahr.² Different writers refer to extensive hot springs on the island of Ngau. They are placed near the beach, and close to an ordinary cool spring. Miss Gordon Cumming in *At Home in Fiji* gives an illustration of them. Horne mentions a hot spring on the island of Rambi. Andrews describes two others that bubble up through the limestone near the tidal zone in the southern part of Vanua Mbalavu. Both these springs are in close proximity to the junction line between the intruded andesite and the old reef rock. One of them, though not boiling, was hot enough to scald the skin.³ This list is no doubt capable of being much extended, especially for Viti Levu and the Lau Group.

A description of the several systems of thermal springs of Vanua Levu will now be given.

I. THE HOT SPRINGS OF THE LOWER VALLEY OF THE WAINUNU RIVER.—This is one of the most extensive systems of the kind in the island. The temperature of the various springs during my sojourn in this district in 1898 ranged from 100° to 130° Fahr. Those known to me are mostly situated in the lower part and at the mouth of the Ndavutu Creek, one of the tributaries of the Wainunu. They open usually on the river-bank, either close to the water or a few feet above it, but some of them find an exit under water at the bottom of the river. Natives allege that hot springs occur at intervals on the left bank and at the river-bottom along the whole length of the river below Ndavutu Creek. There is certainly a hot spring on the right side of the river's mouth near Mr. Dyer's house. It issues from the reef-flat and can only be observed at exceptionally low tides. There is also a hot spring which rises up at the edge of the stream at Thongea (Cogea) nearly

¹ *Journal des Muséum Godeffroy*, heft 14, Hamburg, 1879.

² Dr. Max Büchner also refers to this spring in his *Reise durch den Stillen Ocean*, 1878.

³ *Bulletin Museum Comparative Zoology*, Harvard, vol. 38; Geolog. Series V., No 1, Nov. 1900.

a mile above Nдавutu. If the above statement of the natives is correct, as I believe it is, then these thermal springs issue along a line quite four geographical miles in length extending inland from the mouth of the Wainunu.

All the springs are situated in the tidal part of the river-valley, with the exception of that of Thongea, which is just above this limit. They are but little elevated above the sea-level, those exposed being usually not more than ten feet above the river and often much less. This is a region of basalt, the valley of the Wainunu lying, as described on page 82, in the fold between two great basaltic flows, and probably representing a line of weakness, along which the hot springs issue either from among loose blocks, or from the soil, or from a tufaceous sandstone. They deposit little if any of the siliceous sinter which is often found in the thermal waters of this island. This is due probably to their scanty exposure and to their low temperature. The density of the water is near that of fresh water, being not over 1001. The following temperatures may be useful for comparison with future observations :

Thongea, when not covered by the stream	July, 1898,	127° F.
Nдавutu, bath-spring at Mr. Barratt's house	Usually	100° „
„ on left bank of the creek near the landing place .	June, 1898,	126° „
„ on left bank of creek near mouth	Dec. „	127° „
„ pool in foot-path on left bank	{ June 2, „	112° „
	{ July 27, „	111° „
„ at bottom of main river in depth of 3 feet, close to the left bank and just above the mouth of the Nдавutu creek, self-registering Six thermometer used	{ July „	122° „

2. THE HOT SPRINGS OF NATOARAU AND ITS VICINITY.—This thermal system lies in the lower valley of the Mbale-mbale branch of the river Ndreke-ni-wai. The principal springs are situated at Natoarau, a village about half a mile in a direct line from Mbale-mbale, about three miles from the coast, and only about fifty feet above the sea. They bubble up in pools near brooks, and extend at intervals over an area probably several hundred yards across. Five springs came under my notice ; but there are doubtless several others in the low-lying and often swampy land of this district. No deposits were noticed, but the mode of occurrence and low temperature of the springs serve to explain this fact. The following temperature observations were made by me in March, 1899 :—

- A. Pool 4 feet across, with sides of stone, close to village . . 126° F.
- B. Pool 10 feet wide, a few paces from pool A. 114° „

C. Pool 12 feet wide, 100 yards from village, near the river . 103° F.

D. Pool on the road to Mbale-mbale, mixed with surface water 100° „

The natives and others often state that the thermal springs here and in other localities are much hotter in dry than in rainy weather. This is correct in a sense, because in wet weather the surface water would usually find access to the pools ; but there is no reason to believe that the temperature of the water at the hole of exit varies at all from this cause. The temperature of pool A was taken at the bottom where the water bubbled up ; and probably it represents the true degree of heat of these springs, since in the other cases observation of this point was not so easy. The weather was dry during this visit ; but, three months before, I tested the temperature of this pool after heavy rain, when the district was flooded, and then I got a reading of 127° at the exit-hole of the spring.

Another thermal spring, which is distant about a mile from Natoarau, is known as Waitunutunu, that is, Warm Water. It lies about a third of a mile from the village of Nambuniseseri, between Mbale-mbale and Waisali, and is quite four miles inland and about 100 feet above the sea. The springs bubble up into a pool, about 12 feet across, which is close to a brook and had a temperature in March, 1899, of 109—112° F.

3. THE HOT SPRINGS OF NUKUMBOLO.—The village of Nukumbolo, where the springs are situated, lies on the banks of a tributary of the Vatu-kawa branch of the river Ndreke-ni-wai, and is distant as the crow flies about six miles inland from the river's mouth. The springs issue on a hill-slope from several places a few steps apart, and are removed about a hundred yards from the river, and from 20 to 30 feet above it. Their elevation above the sea would be about 130 feet. The temperature taken in the two hottest places was 157° F, in November 1898, and 158° in the following February. As in the case of the springs of Savu-savu and a few other localities, the rocks are coated with siliceous sinter mixed with carbonate of lime, and a gelatinous incrusting alga grows on the borders of tiny hollows bathed often in water of a temperature 137–140°, but thriving most where the temperature is 115–120°. The water runs down the slope into a series of pools made by the natives for bathing, the temperature of the lowest pool being 103–105° and of the highest 120°. This is one of the best localities I have seen in the island for the erection of thermal baths. The rock pierced by the springs is apparently a basic agglomerate-tuff. Large blocks of a hard and somewhat altered palagonitic tuff lie around the bathing pools.

4. THE BOILING SPRINGS OF SAVU-SAVU.—These springs figure in all the descriptions of the group, and they are also famous amongst the natives. Since they were described by Wilkes, who visited them in 1840, in his narrative of the United States Exploring Expedition, many accounts of them have been written by subsequent visitors; not infrequently they have been sketched as well as described; and several analyses of their waters have been made.¹ The accounts of these springs that lie before me extend at intervals over a period of nearly sixty years; but I shall allude to them only so far as they throw light on the history of the springs during this period.

The principal springs are situated in a slight hollow in a more or less level tract extending in from the beach, and are distant about 150 yards from the shore and about ten feet above the sea-level. They are five or six in number, and at the time of my visits in July and November, 1898, they were boiling briskly, the thermometer readings being 208–210° F., but the mercury probably fell two or three degrees in withdrawing the thermometer. When, as was the case when Wilkes visited this locality in 1840, there is but a slight appearance of boiling, brisk ebullition is produced by covering them over with leaves. The natives call this locality Na Kama, which signifies “the burning place,” and employed the springs extensively for cooking their food. Just as Wilkes describes, a freshwater brook runs past the springs and receives their outflow. The temperature of the brook immediately above the springs is that of an ordinary freshwater stream 75–76° F.; but below it is scalding. The account given by Wilkes of the spring and of the brook in 1840 applies to them in our own time. The small stones lying in the effluent channels of the springs are incrustated with siliceous sinter, and a green alga lines the sides, bathed generally in the steam but sometimes partially immersed in water only a few degrees below the boiling point. It is noteworthy that this alga which was flourishing in July was all dead in November.

The scalding water also oozes through the sand of the adjacent beach in abundance for a distance of at least some hundreds of

Amongst the other descriptions of these springs I may refer to that of Kleinschmidt in the work quoted on p. 22, to that of Miss Gordon Cumming in *At Home in Fiji*, to that of Horne in his *Year in Fiji*, &c. They are sketched in the descriptions of Kleinschmidt, Miss Cumming, and Commodore Wilkes. The analyses are given on a later page together with the references.

yards. It is even stated that as far as Ndaku, a mile to the westward, the hot springs issue at intervals through the beach.¹ There are evidently also extensive submarine springs close to the beach ; and probably Wilkes was not far from the truth when he remarked that the "whole area of half-a-mile square seems to be covered with hot springs."

Off the beach, a few hundred yards to the westward of the springs, is a batch of dead reef formed of massive corals and only approachable from the shore at extreme low-tide when it is a little exposed. From numerous small holes and cracks in the dead-coral hot water issues almost at the boiling point (210° F). It is apparent that these springs have appeared at this particular spot since the corals grew. But it is remarkable that this has been apparently going on since the visit of Wilkes in 1840. He refers to a coral rock, distant one-third of a mile from the springs and 150 feet from the beach, through which boiling water was issuing in several places. This rock which was then 10 feet wide and 20 feet long, was at his visit exposed for three feet at low-tide and covered at high-tide.²

The geological characters of this locality are described on page 191. I may here remark that if these thermal springs occupy the position of an old crater, it would require much imaginative power to restore it now. The off-lying small island of Nawi might by its situation appear to countenance this idea, but I found no special indication, when I examined it, in support of this view. From the geological character of the district, I would infer that if a crater once existed here it was submarine and that it has been long since obliterated by marine and aerial denudation. The boiling springs come up through apparently a rotten volcanic agglomerate. The slight hollow of three or four feet deep, in which they lie, was considered by Kleinschmidt to be an old crater cavity ; but it is only 40 or 50 feet across, and in the earlier descriptions the hollow is described as surrounded by a mound of earth. As shown below, the natives themselves may be held responsible for many changes

¹ *Pacific Islands, Sailing Directions*, vol. ii., Central Groups, 1900, p. 185.

² From what I remember the usual exposure at low-water in 1898 was less than a foot. I have little doubt as to the identity of the locality. This rock is one of the "sights" of the place at the present time. It would be interesting for a resident to compare carefully its present condition with that as described by Wilkes. Dana in the work quoted on p. 10, refers to this rock as a knoll of basalt ; but he never visited the locality and only obtained his account from the officers of Wilkes.

in the surface around the springs. There is, in fact, no trace of a crateral cavity in this district now.

I will now briefly notice the history of the boiling springs since 1840, when they were visited by Commodore Wilkes. At that time there were five springs, situated in a basin 40 feet across, and possessing a temperature of 200—210° F. Although there was scarcely any appearance of boiling, rapid ebullition could be excited by covering the springs with leaves and grass. The natives alleged that the springs had always been in the same condition. In 1863, when the Chief of Wainunu (Tui Wainunu) came to fight the Savu-savu people, he endeavoured but without success to choke up the springs by heaping earth over them. I was informed of this circumstance by Mr. A. H. Barrack, the owner of the springs. Miss Gordon Cumming also refers to it in her book *At Home in Fiji*. When this lady visited the springs in August, 1876, they were intermittent in their action, the highest making a fountain two to three feet high. According to the description of Kleinschmidt they were in the same intermittent condition in May of the same year. There were then four springs situated in a bowl-shaped hollow. The two larger springs were not constantly bubbling up, but displayed periodic ebullitions of about twenty minutes' duration, the waters disappearing in the intervals. The other two springs were not then active. Horne, who visited this locality in 1878, refers to three or four principal springs situated in the centre of a hollow, which was surrounded by a mound of earth, the water boiling up to the height of about a foot.

About this time the springs entered for a while into a new phase of action and assumed the form of geysers. According to information received from Mr. A. H. Barrack and other old residents in Savu-savu, the waters spouted up to a height of from 40 to 60 feet, not vertically but at an angle. Each outburst, which lasted for ten or twenty minutes, was followed by a similar interval of repose, during which the springs dried up. This continued for a month or two, after which the springs gradually resumed their normal level. When I visited the springs in July and November, 1898, they were boiling briskly, attaining a height of a few inches, and showed no signs of intermittent action.

I come now to the different analyses that have been made of the water of these thermal springs of Savu-savu. Specimens have been analysed at different times by chemists in various parts of the world, in America, in Germany, in Australia, etc, and the results as far as known to me are now appended.

A. Analysis by Dr. C. T. Jackson of Boston, U.S., of the water obtained in 1840 by the Wilkes Exploring Expedition.¹

Specific Gravity 1'0097. Temperature 57° F.

The evaporation of a quantity equal to 1000 grains of distilled water gave 7'2 grains of salt, thus composed :—

Chlorine	3'577
Sodium	1'665 or Soda 2'238.
Magnesia	0'440
Lime	0'366
Silica and iron with a trace of phosphate of lime	0'200
Carbonic acid	0'493
	<hr/>
	6'741
Organic matter and loss	0'459
	<hr/>
	7'200

B. Analysis by Dr. Oscar Pieper of Hamburg of the water obtained by Mr. Kleinschmidt in May, 1876.²

The report stated that the water was clear, neutral in reaction and salt-bitter in taste, brown flakes of hydrated iron oxide occurring in it after long standing. The dissolved salts amounted to "8'48 g. per litre," and the remark is made that "the concentration is therefore not so great as in sea-water." The solid constituents consisted in by far the greatest part of Natrium and Calcium chlorides. A quantitative determination, which on account of the small quantity of the water was confined to "eine Chlor und Kalkbestimmung," gave this result :—

Chlor (Chlorine)	4'79 g. per litre.
Kalk (Lime)	2'31 " "

Reckoned as Chlornatrium (Kocksalz) and Chlorcalcium, these results were obtained :—

Chlorcalcium (Calcium chloride)	4'55 g. per litre.
Chlornatrium (Sodium chloride)	3'09 " "

Amongst other constituents found in small quantities were Sulphuric acid, Silicic acid (Kieselsäure), Potash, and Iron oxide. Iodine, Bromine, Nitrates, and Borates were completely wanting. "If this water," says Dr. Pieper, "has healing properties, it does not owe them to its chemical composition."

¹ *Narrative of the United States Exploring Expedition*, III., 199, by Commodore Wilkes. See also Dana's *Geology* of the same expedition.

² *Journal des Museum Godeffroy*, heft 14, Hamburg, 1879.

C. *Analysis by Mr. H. Rocholl of sample obtained by Mr. H. Stonehewer Cooper probably in 1877 or 1878.*¹

Total solids at 212° F.	'8796 per cent.
" " ignited	'7726 " "

The residue consisted of—

Free Sulphuric Acid (SO ₃)	'0049 " "
Calcium sulphate	'0260 " "
Calcium chloride	'4355 " "
Magnesium chloride	'0021 " "
Potassium chloride	'0415 " "
Water	'1070 " "
Sodium chloride	'2641 " "

'8811

D. *Analysis by Prof. Liversidge of the Sydney University of a sample of the water collected by Dr. Bromlow, R.N., about 1879.*²

The specific gravity was 1·0064 at 60° F. The total solids in solution were 582·4 grains per gallon ; but when heated to a dull red heat, the residue was 546·9 grains per gallon, the combined water having been driven off. Iodine and bromine were carefully sought for, but in vain. Four pints of the water were examined.

COMPOSITION.

	Per cent. in residue.	Parts per million of water.	Grains per gallon.
Silica, insoluble	1·681	133·3	9·20
Silica, soluble	'074	5·8	'40
Alumina and traces of Iron sesquioxide	'534	41·7	2·92
Aluminium chloride	1·646	128·6	9·00
Phosphoric acid	traces	traces	traces
Calcium chloride	46·754	3,652·9	255·70
Calcium sulphate	4·770	372·7	26·09
Magnesium chloride	'154	12·0	'84
Sodium chloride	42·171	3,294·8	230·64
Potassium chloride	1·756	137·2	9·60
Carbonic acid	traces	traces	traces
Loss	'460	34·0	2·52
	100·000	7,813·0	546·91

Looking at the general character of these thermal springs of Savu-savu we may quote the remarks of Prof. Liversidge and Dr.

¹ *Islands of the Pacific*, by H. Stonehewer Cooper, 1888 edition.

² *Journal Royal Society*, New South Wales, 1880, vol. 14. Miss Gordon Cumming in *At Home in Fiji* gives the same analysis but differently stated.

Pieper that the salts in solution consist for the most part of chlorides, the chlorides of calcium and sodium largely prevailing.

COMPARISON OF THE ANALYSES OF THE WATER OF THE SAVU-SAVU THERMAL SPRINGS, STATED IN GRAINS PER THOUSAND OF WATER.¹

	Date collected.	Chlorine.	Sodium.	Calcium.	Calcium chloride.	Sodium chloride.	Total salts.	Density.
Dr. Jackson	1840	3.57	1.66	0.36	—	—	7.20	1.009
Dr. Pieper	1876	4.79	—	2.31	4.55	3.09	8.48	—
Mr. Rocholl	1878	—	—	—	4.35	2.64	8.81	—
Prof. Liversidge . .	1879	(4.50)	(1.29)	(1.42)	3.65	3.29	7.81	1.006
Sea-water, tropics		19.46	11.08	0.46	—	—	35.00	1.02

It is to be inferred from the above that the quantity of salts in solution remains about the same, the proportion varying only in the four analyses, which extended over a period of forty years, between 7.2 and 8.8 grains per thousand grains of water. This is considerably less than the salts in solution in sea-water, namely 35 grains per thousand. The relative proportions of the salts, excepting those of calcium, do not vary more than we should expect in the case of analyses made by varying methods and probably with a varying degree of exactness.

Dana² considered from Dr. Jackson's analysis that the water of the Savu-savu springs is probably of marine origin; but the absence of bromine and iodine, as especially remarked by Dr. Pieper and Prof. Liversidge does not support this view. We might also expect the proportion of the salts to each other to show a greater similarity to that in sea-water than they do. On the other hand the total volume of water discharged, not only by the springs proper but for several hundred yards along the beach, and also between the tide-marks and beyond, must be far greater than could be supplied by the rainfall of this portion of the Savu-savu peninsula, which is only one and a half to two miles across and 800 feet high. We must look, I think, for the source of these waters in deep subterranean streams or artesian basins that would be fed by the rains precipitated in the mountainous districts where the rainfall amounts to at least 200—300 inches in the year.

¹ To avoid error, I have given the results of each without converting them to a common standard. The numbers in brackets are taken from the form of Prof. Liversidge's analysis given in Miss Gordon Cumming's book.

² *United States Exploring Expedition*, vol. 10, Geology.

This matter is further discussed in my general remarks on the hot-springs of this island (page 38).

5. THE HOT SPRINGS NEAR RAVUKA.—These springs rise up in the centre of the breadth of the island about nine miles direct from the coast. They are about 200 feet above the sea and are situated on the Ndrawa branch of the Ndreketi River some two miles below the hamlet of Ravuka. They are on a small scale and ooze through a bed of rounded blocks and pebbles close to the water on the left bank. Their temperature in August, 1898, was 148° F. They are covered by the river when it is swollen by the rains, and very probably other hot-springs issue along the river-bottom. The conditions are not suitable for the formation of deposits.

6. THE HOT SPRINGS OF VUINASANGA.—These thermal springs are also situated in the heart of the island on a tributary of the Ndreketi some three or four miles westward from Va Lili and about 150 feet above the sea. On each bank of the river four or five paces from the water and three or four feet above it, there is a small pool two to four feet wide. In June, 1899, the pool on the right bank had a temperature of 131° F., and that on the left bank of 134° . There were no deposits.

7. THE HOT SPRINGS ON THE SOUTH SIDE OF THE NAWAVI RANGE.—These springs also lie within the borders of the valley of the Ndreketi. They may be "located" by describing them as lying a few miles inland from the north coast fronted by Mathuata Island. I did not visit them and have only learned of them from Mr. Thomson's Mathuata paper.¹ That gentleman refers to them as two in number and situated at the back of the coast range about four miles inland from the village of Nangumu; but no particulars are given.

8. THE HOT SPRINGS OF VATULOALOA.—These springs lie on the Mathuata Coast in the neighbourhood of Mathuata Island. I have not seen them, but am indebted to Mr. Thomson for the particulars here given, which are taken from his paper above quoted. Mr. Thomson, who discovered them in 1880, named them the "Graçie" springs. They issue below high-water mark at Vatu-loaloa, and had a temperature in 1880 of about 140° F. They are said to possess many valuable healing qualities.

¹ *Proceedings*, Queensland Branch, Geographical Society, Australia, vol. 1. 1886.

9. THE HOT SPRINGS OF NAMBUONU.—These springs are situated on the same part of the Mathuata coast as those of Vatuloaloa above referred to. I learned from Mr. Bulling of Undu Point that they issue from swampy ground half a mile inland. They were discovered accidentally by a Japanese who put his foot into them, the temperature being sufficiently high to scald the feet, but not at the boiling-point, probably about 140° F.

10. THE HOT SPRINGS NEAR TAMBIA.—These extensive springs, situate $1\frac{1}{2}$ to 2 miles inland, and rather under 100 feet above the sea, lie near the Mathuata or north coast of the island, some four miles west of the Wailevu river. They rise up in the midst of level country about a mile from the town of Tambia, and near the village of Ngovungovu. Although situated in the valley of the Tambia river, these springs are not adjacent to the river, and in this respect they differ from nearly all the inland hot springs. The hottest spring bubbles up into a pool 5 or 6 feet across, which had a temperature of 180° F., in March, 1899. Near by is a large deep pool, some 20 feet or more across, with a temperature of 100°. It receives the overflow from the smaller pool, and apparently hot water also bubbles up at the bottom. Around the smaller hottest pool there is a considerable deposit of what is mainly siliceous sinter. It incrusts the stones and also the oyster-shells lying about the pool in quantities, where they have been left by the natives after their contents had been cooked and eaten. Some of the shells are almost decayed away, the sinter for the most part alone remaining.

11. THE HOT SPRINGS OF VANDRANI.—These springs occur in the heart of the island, about 8 miles from the coast in a straight line, and about 270 feet above the sea. This is the greatest elevation, as far as I know, at which a hot spring exists in this island. Here they rise up near the base of the central mountain range, close to the head-waters of the Wailevu river which opens into Lambasa bay. The springs bubble up into a pool, a foot deep, on the left side of the river, four or five paces away from the water's edge, and scarcely raised above it. They are covered over when the river is in flood. In February, 1899, the temperature recorded by my thermometer was 100° F.; but probably it was a few degrees higher at the bottom of the pool. I noticed no deposits.

12. THE HOT SPRINGS OF NA KAMA ON THE WAILEVU RIVER.—These boiling springs, which are of an extensive character,

come up in half-a-dozen places on either bank of the river, and are from 5 to 6 miles inland, and about 90 feet above the sea. They are close to the water, and from 1 to 10 feet above it. The temperature of one small pool, where the water bubbled up briskly, was 204° F. in February, 1899. In another it was 194° . The water was probably at the boiling-point in some cases as it entered the pools, and in the others it could have been only a few degrees below it. The rocks of the district are agglomerates and tuffs. I have no recollection of deposits of any extent around the springs.

13. THE HOT SPRINGS OF VUNIMOLI ON THE LAMBASA RIVER.—A few minutes' walk from Vunimoli, and about 100 yards from the left bank of the river, these hot springs issue in a place named Vunimbele from the foraminiferous clay rock (soapstone) of the district. They are on the side of a ditch which communicates with the river. The natives have cut out of the soft rock small square basins which receive the waters. The temperature of the hottest spring in August, 1899, was 155° F. That of others was 140° . The conditions are not favourable for the formation of deposits. These springs lie about 8 miles inland and are rather over 100 feet above the sea. They are, however, small and unimportant, and the locality in which they occur is now overgrown with vegetation and not easy to discover.

14. THE HOT SPRINGS OF MBATI-NI-KAMA ON THE NGAWA RIVER.—These springs are situated in the Lambasa district about 7 miles from the coast, and rather over 100 feet above the sea. They issue copiously from the volcanic agglomerate at a temperature of 161° F. (August, 1899), and are only removed a few paces from the river, and a foot or so above it. Algæ flourish in the water, and siliceous sinter incrusts the rocks.

15. THE HOT SPRING OF NANDONGO ON THE HEAD-WATERS OF THE WAI-NI-KORO RIVER.—A few hundred yards from the village and elevated about 180 feet above the sea there is a small pool in the clay of the river bank, 2 or 3 feet above and close to the water, which in September, 1899, had a temperature of 97° F.

16. THE HOT SPRINGS OF NATUVO ON THE NORTH COAST OF NATEWA BAY.—About a mile east of Mbiagunu and near the village of Natuvo, there are two hot springs of small size which I visited in August, 1899. One that issued on the reef-flat from the coral-rock at a temperature of 136° F. was covered over towards

high-tide. The other issued near by at a temperature of 131° from swampy ground a few paces among the trees.

17. THE HOT SPRINGS OF NDAKU-NDAKU ON THE NORTH COAST OF NATEWA BAY.—At this place about 2 miles north of Vuinandi some hot springs rise through the reef-flat, which are only exposed at low tide. At the time of my visit they were covered over by the rising tide. The natives described them as not very hot and like the neighbouring hot springs of Natuvo.

18. THE HOT SPRING OF NAVA KARAVI, NATEWA BAY.—The coast village thus named lies about one and a half miles north of Were-kamba. The hot spring is about a mile inland and not over 30 to 40 feet above the sea. It is reached after traversing a low and often swampy tract. The spring in August, 1899, issued from a little rise at a temperature of 133° Fahr., and formed a rivulet 18 inches across.

19. THE HOT SPRINGS OF VUNISAWANA AT THE HEAD OF NATEWA BAY.—Mr. Horne, who was in this locality in 1878, refers to these springs in his book *A Year in Fiji*. They had at one time, he remarks, a wide reputation for their curative qualities; but the people around became so poor on account of the hospitality that custom compelled them to extend to the numerous visitors that they buried up the springs. Mr. Horne was shown the site at the bottom of a muddy creek. I saw it in 1898. It lies 300 or 400 yards in from the beach and only a few feet above the sea. There were no signs of heat then; but I was told that when the stream close by is very low it sometimes is a little warm.

20. THE HOT SPRING OF NDREKE-NI-WAI ON THE SOUTH COAST OF NATEWA BAY.—This small spring issues between the tide-marks from an old reef-patch close to the shore and is only to be seen at low-water. Its temperature in May, 1898, was $130-135^{\circ}$ Fahr.

21. THE HOT SPRING OF WAIKATAKATA ON THE SOUTH COAST OF NATEWA BAY.—This important spring lies about four miles east of the town of Natewa. It issues on a hill-slope about 400 yards from the beach and is some 25 or 30 feet above the sea; but it is so beset by undergrowth that the source is not easy to reach. Boulders and blocks of a basaltic rock lie about on the slope; and it is from under a huge boulder of five or six tons in weight that the spring emerges at a temperature of 148° Fahr. (April, 1898). There is a good volume of water, and a series of bathing pools of

varying temperature could be readily made. Unlike most of the inland hot springs, it is not in connection with a stream or river.

22. THE HOT SPRING OF NDEVO ON THE COAST OPPOSITE TO RAMBL.—I did not hear of any spring when in the locality; but I learned afterwards that near a stream on the beach there is a hot spring which is covered at high tide.

23. THE HOT SPRING OF NAVUNI NEAR FAWN HARBOUR.—This small spring is situated in a hilly district in a region where olivine-basalts prevail. I was indebted to Mr. Pickering for showing me its locality. It lies about three-quarters of a mile inland and about 100 feet above the sea. It issues from the volcanic agglomerate a few paces from the right bank of the Navuni stream and five or six feet above its level. In May, 1898, it had a temperature of 112—113° Fahr.

GENERAL REMARKS ON THE HOT SPRINGS

This island is therefore remarkable for the number of its hot springs. In the list given on page 40 I have enumerated 23 localities where they occur; but, as shown below, their number will probably in time be extensively increased.

On referring to the map it will be observed that the distribution of these springs is fairly general over two-thirds or three-fourths of the island. Taking this area at about 1,500 square miles and dividing it into squares with sides of eight miles, we should, if the springs were quite evenly dispersed, find a thermal system in every square. Even amongst the Fijians and among the white residents the number of hot springs will cause surprise. Only those of Savu-savu, Wainunu, Nukumbolo, Mbatini-kama, and Na Kama on the Wailevu river have been up to this time generally known. The reason of this is that most of them are insignificant, and with a temperature far below the boiling-point, and ooze up in unlikely and out-of-the way places, as by the water-side in little visited river-valleys, on the reef-flats of not much frequented coasts, and in swampy situations where they are likely to be overlooked. The natives only recognise as "Na Kama" the boiling or very hot springs; and it was only after much questioning that I could get them to tell me of some unimportant "wai katakata" (hot water) which they deemed to be far beneath my notice. The natives were scarcely interested in my botanical and geological investigations; but they considered it to be beneath the dignity of a man who had seen the wonders of Na Savu-savu to spend some time looking for

a half-forgotten thermal spring in a swamp. From this cause alone I no doubt failed to find several springs. All the boiling springs and those of very high temperature are probably known ; but as pointed out below it is more than likely that a large number of unimportant springs remain to be discovered in many a desert inland valley and between the tide-marks along the very extensive reef-bound coasts.

As above remarked the hot springs did not come under my notice in all parts of the island. They are to all appearance wanting in the western or Mbua portion, and also in the Undu portion north of Natewa Bay. Taking the first-named region, it will be noticed that no hot springs are indicated in the map west of the Ndreketi and Wainunu rivers. I made inquiries wherever I went but with no result. On my writing to Mr. Wittstock, of Mbau lailai, who is well acquainted with the Mbua peninsula, he informed me that if hot springs existed in that part of the island he would probably have known of them. In that portion of the island which ends in Undu Point I could neither discover nor hear of any thermal springs east of Lambasa on the north side, and of Lakemb on the south or Natewa Bay side ; nor could Mr. Bulling, who has resided at Undu Point for many years, tell me of any springs in his neighbourhood.

On looking at the general map it will be observed that the hot springs are confined to the area of basic rocks, although they do not occur all over that area, not being indicated in the map to the west of the Ndreketi and Wainunu rivers. They are not known to occur in the region of dacites and acid andesites, as in the case of the Drandramea district ; and they have not been found in the area of rhyolitic and trachytic rocks that extends from Undu Point to Mbuthai-sau on the north coast and to near Tawaki on the Natewa Bay side. The region of hot springs would be limited to the east by a line joining the Mbatini-kama springs with those of Nandongo on the Wainikoro river and Natuvo on the north shore of Natewa Bay. Such a line, though lying within it, roughly indicates the limit between the regions of basic and acid rocks.

The situation of the hot springs in the lower levels, and the non-discovery at elevations exceeding 300 feet above the sea, are facts of importance. In more than half the cases they arise close to and often on the banks of streams and rivers, occasionally indeed at the river-bottom ; and no doubt numerous unknown thermal springs issue under water from the river beds. In about a third of the known cases the springs come up on the coast between the

tide-marks, usually rising through the reef-flat. At times even they are to be observed below the low tide level; and one can scarcely doubt that there are a large number of undiscovered springs that are never exposed at the lowest tides. It is also very likely that a number of hot springs issuing between the tide-marks are still to be discovered without much difficulty.

The same may be said of inland hot springs. Looking at the insignificant character of many of them and noting their occurrence in places where they might easily be overlooked, it is highly probable, as before remarked, that a number of springs exist inland, which, though once known to the natives, are now forgotten. The interior of the island is very sparsely inhabited now; but there is evidence of a much more populous condition in old times. The present natives are fast losing the knowledge of the interior of the island which their forefathers possessed; and many tracts in the mountain districts are far removed from existing paths. From the haphazard manner in which I lighted upon thermal springs beside the head-waters of the Ndreketi, Wailevu, and Wai-ni-koro rivers, I cannot doubt that many more exist in similar localities not visited by me.

With regard to the distribution of the springs as respecting temperature, I cannot find any marked arrangement either in their grouping or in the amount of elevation. It is noticeable, however, that the three systems of hottest springs, that of Savu-savu (210°), that of Na Kama on the Wailevu river (204°), and that of Tambia (180°) are all less than 100 feet above the sea. Although the springs of highest temperature are confined generally, with the exception of those of Savu-savu, to the main mass of the island, it would seem that adjacent systems of springs may differ much in temperature. The springs of Vunimoli, for instance, have a maximum temperature of 155° , which is nearly 50° lower than that of Na Kama, three miles to the westward. Hot springs are more numerous in the region around Lambasa than in most other districts. Lastly, I may add that earthquakes are apparently more frequent in the Mua district, where no thermal springs are known, than in any other part of the island.

With regard to the deposits formed around the springs, it may be observed that the circumstances are not usually suitable for their formation, as for instance when they rise through the reef-flat or in swampy localities. In those springs, however, where the temperature is over 150° F., and where the water spreads over a surface so as to facilitate evaporation, deposits of white sinter associated

with algæ occur, as at Savu-savu, Tambia, and Nukumbolo. Its composition varies a little in different localities. At Savu-savu it is compact and laminated and formed almost entirely of hydrated amorphous or colloid silica. At Mbatini-kama the siliceous sinter is more friable, with a tendency to form opal. The sinter of the Nukumbolo springs resembles that of Savu-savu; but it also contains a good proportion of carbonate of lime (20 per cent.) in a granular form, and that of Tambia has the same characters. It is not unlikely that this lime is derived from the decayed shells, such as I have referred to in the case of the Tambia springs. It may be here observed that Mr. Weed and others, who have studied the origin of siliceous sinter in the Yellowstone region and elsewhere, regard it as the secretion of algæ, mosses, &c., that grow in hot waters (*American Journal of Science*, vol. 37, 1889).

I come now to some general considerations respecting the hot springs of Vanua Levu. In the first place there is the singular fact that the inland hot springs nearly always make their appearance along the present lines of surface-drainage. But I do not gather that the hot springs are of more recent origin than the rivers and streams, by the side of which they rise. On the contrary the hot springs are probably far older. The conditions of subterranean drainage that favour the formation of springs at the surface, whether cold or thermal, would no doubt often determine the direction of surface drainage in a newly-formed land. Those familiar with modern volcanoes will recall the absence or rarity of streams and rivers, and the frequency often of cold and thermal springs at and near the coast, which are sometimes of such bulk at the exits that the expression "subterranean river" would be nearly appropriate. The presence of artesian reservoirs may also in some localities be safely assumed. I will here draw a little on my own experience of volcanic regions.

On the lava-bound coasts of the riverless southern portion of the large volcanic island of Hawaii, the subterranean waters issue as cold and thermal springs at numerous localities. At Punaluu, and at Ninoli, a mile to the westward, there are extensive fresh-water springs at and near the beach which have a temperature of 64° F. all through the year,¹ those at Ninoli issuing as a large subterranean stream. East of Punaluu and at intervals along the Puna coast, springs of water, sometimes fresh and cold with a

¹ I took the temperature at monthly intervals between October, 1896, and September, 1897. The mean annual temperature of the air in the shade would be about 64° at an elevation of between 3,000 and 4,000 feet.

temperature occasionally as low as 64° , at other times mineral and thermal, but with a temperature not usually above 95° , issue at the surface or at the bottom of deep fissures in the old lava flows. . . . In Oahu, another island of the Hawaiian group, where the volcanic forces have been long extinct, artesian wells have been in extensive use for some years in the irrigation of the sugar-cane plantations. The last water-bearing strata are reached at depths of 400 to 500 feet.¹ The subterranean or artesian reservoirs are evidently therefore on a large scale; yet Oahu is scarcely one-third the size of Vanua Levu in Fiji. . . . Lastly, I will refer to the numerous subterranean streams that issue forth, as cold and thermal springs, from beneath the lavas near and at the Etna coast, as for instance in the vicinity of Acireale. The Etna slopes are in great part deforested, and in consequence soakage is relatively small, and after heavy rains much of the water runs off in the torrents. Whilst in this locality I was impressed with these facts, and I formed the opinion that in ancient times when Etna was well wooded the discharge of subterranean streams at the coast was far greater than at present.

For these reasons and on other grounds, amongst them notably the absence of recent crateral cavities, I infer that the numerous hot springs are the outflows of subterranean streams, fed originally by the "soakage" arising from a rainfall of at least 200 to 300 inches in the mountainous portions of the island. Such subterranean streams run probably at considerable depths, emerging, it is likely, as often under the sea as they do on the land.

Since writing the above I have read in the Journal of the Royal Geographical Society (November 1902), an abstract of a lecture by Prof. Suess on the subject of hot springs and volcanic phenomena. Thermal springs, he holds, are supplied by hypogene waters and do not receive their salts from the sea. Such springs, according to this view, being the survivals of volcanic activity, originate in the depths of the earth's crust and bring water to the surface for the first time, not deriving it from infiltration. It seems almost impertinent to suggest a view opposed to that of such a high authority; but it appears to me that the frequent situation of the Vanua Levu thermal springs along the lines of surface-drainage requires an explanation that does not altogether exclude the agency of infiltration.

¹ At Ewa there are pumping plants capable of supplying 75 million gallons a day, the water being drawn entirely from artesian wells. (*Report on Hawaii*, by Dr. Stubbs, bulletin 95, 1901; U.S. Department of Agriculture.)

LIST OF THE HOT SPRINGS OF VANUA LEVU, 1898-99.

Locality.	Coast or inland.	Height above sea-level.	Near or far from streams.	Siliceous sinter.	Nature of surface at the exit.	Temperature.
1. Wainunu . .	Coast to four miles inland	Sea-level to 20 or 30 feet	River-side and under water.	Little or none .	Soil-cap, tuffs, &c. .	100°-130° F.
2. Natorau and vicinity	Three to four miles from coast	50 to 100 feet . .	Near brooks and streams .	Little or none .	Soil-cap	110°-126° F.
3. Nukumbolo .	Six miles inland . .	130 feet	About 100 yards from river .	Mixed with lime carbonate	Agglomerate-tuff . .	157° F.
4. Savu-savu .	Beach and 150 yards inland	Sea-level to 10 feet	Inland springs near a brook	In fair quantity .	Rotten volcanic agglomerate	208°-210° F.
5. Ravuka . .	Nine miles inland . .	200 feet	River-side	None	Pebble bed	148° F.
6. Vuinasanga .	Ten miles from north coast	150 feet	River-side	None	Soil-cap	131°-134° F.
7. Foot of Nawavi Range	Four miles inland . .	Not known . . .	Not known	Not known . . .	Not known	Not known.
8. Vatuloaloa .	Coast below high-tide mark	Nil. . . . .	. . . . .	. . . . .	. . . . .	140° F.
9. Nambuonu .	Half-mile inland . .	Probably slight . .	Not known	Not known . . .	Swampy	140° F. (probably).
10. Tambia . .	Inland one and a-half to two miles	90 feet	Not near a stream	Abundant	Soil-cap	180° F.

11. Vandrani . . .	Eight miles from coast	270 feet	River-side	None	Old river-bed	100° F.
12. N a K a m a, Wailevu	Inland five to six miles	90 feet	River-side	Probably little	Agglomerates and tuffs	194°-204° F.
13. Vunimoli . . .	Inland eight miles .	120 feet	About 100 yards from river .	None	Foraminiferous clay- rock	{ 140° F. 155° F.
14. Mbatini- kama	Inland seven and a- half miles	130 feet	River-side	In fair quantity	Volcanic agglomerate	161° F.
15. Nandongo . .	Inland four miles . .	180 feet	River-side	None	Clay	97° F.
16. Natuvu	Coast and between the tide-marks	Nil and a few feet	. . . . .	None	Reef-flat and swampy ground	{ 131° F. 136° F.
17. Ndaku-ndaku	Between the tide- marks	Nil . . . . .	. . . . .	None	Reef-flat	Not known.
18. Navakaravi .	A mile inland	30 to 40 feet	Swampy ground	None	Soil-cap	133° F.
19. Vunisawana .	From beach 300 or 400 yards	A few feet	Near a brook	Not known	Soil-cap	Not known.
20. Ndreke - ni - wai	Coast between the tide-marks	Nil . . . . .	. . . . .	None	Old reef-patch	130°-135° F.
21. Waikatakata	Inland 400 yards . .	25 or 30 feet	Not near a stream	None	Rises beneath a boul- der of basalt	148° F.
22. Ndevo	On coast below high- water level	Nil	Near a stream	Not known	Probably the reef-flat	Not known.
23. Navuni	Inland three-quarters of a mile	100 feet	Near a stream	Little or none	Volcanic agglomerate	112°-113° F.

Summary of the previous remarks on the hot springs of Vanua Levu.

(1) Hot springs have been recorded from 23 localities, but there are probably many undiscovered or forgotten.

(2) They are distributed over much of the island ; but have not been observed in the Mbua or Western end and in the Undu extremity east of Lambasa and Lakemba.

(3) They are confined to the areas of basic rocks and are not known in the districts of dacites and other acid andesites or in those of quartz-porphyry and trachyte.

(4) They are always found at low elevations, never exceeding 300 feet.

(5) Whilst more than half are situated along river and stream courses, nearly all the remainder lie between the tide-marks.

(6) In only two localities is the temperature at or near the boiling-point. In one place it is 180° F., and in most of the other springs it ranges between 100° and 150° .

(7) Siliceous sinter is formed where the temperature is over 150° .

(8) As exemplified by the water of the Savu-savu springs the proportion of salts in solution (8 per 1000) is constant over many years ; whilst in this fact and in the relative amounts of each salt there is a sharp distinction from the composition of sea-water.

(9) The hot springs are older than the streams and rivers, along which they are so frequently found.

It would appear that they are largely supplied from the "soakage" of the heavy rainfall in the mountains.

CHAPTER IV

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES OF VANUA LEVU.

IN this chapter the detailed description of the island is commenced, beginning with the western extremity and proceeding eastward. Most of the petrological details are dealt with under their respective sections ; but it has been found necessary also to frequently refer to them in this connection.

THE NAIVAKA PENINSULA.—This mountainous peninsula forms the conspicuous feature of the western extremity of Vanua Levu. Amongst all the mountains of the island its appearance from a distance gave most promise of displaying the products of recent volcanic eruptions ; but as shown below it affords evidence of an antiquity nearly as great as that of the rest of the island, although there are reasons for believing that its eruptions took place during the last stage of the emergence.

Naivaka is connected with the adjacent relatively little elevated part of the main island by a low and narrow neck a little less than a mile in breadth. In its highest part, where it is only raised between 20 and 30 feet above the sea, this isthmus is formed of the basic volcanic rocks of the district ; but about three fourths of its width are occupied by mangrove-swamps which are especially extensive on the south side.

Viewed from some miles to the eastward the mountain has a regular conical outline ; but from the south, when seen from Rukuru Bay, it has an elongated and a much more irregular profile, descending rapidly on the east side, but displaying a gradual and a fairly regular slope of about 10 degrees on the west side. The upper part of the mountain is in the form of a curve with the concavity facing south, the crest being more or less broken up into five or six peaks showing often precipitous and at times vertical

rocky faces having a drop of from 100 to 300 feet, the highest peaks ranging from 1500 to 1658 feet above the sea.

All around the mountain, except on the upper steep portion on the south side where it is well-wooded, the slopes have the usual character of the "talasinga" districts, being occupied only by grass, ferns, cycads, and the ordinary scanty vegetation of such regions. Whilst on most sides the surface configuration is fairly regular and the ascent to the summit is more or less regular, on the south side bold spurs with valleys between them descend to the coast, and the central mass rises abruptly in the middle of the peninsula from a height between 300 and 500 feet above the sea. It is on this side that Naivaka has the appearance of having been originally a crateral mountain, of which, however, only the north segment in a much degraded condition now remains, whilst the other two-thirds have disappeared.

The prevailing rocks are a blackish compact olivine-basalt, having as a rule much smoky glass in the ground-mass and possessing a specific gravity of 2.92—2.94. They are referred to in the description of genus 25 of the olivine-basalts given on page 259.

These rocks compose the agglomerate and the agglomerate-tuffs that form the eastern portion of the summit and probably most of the elevated part of the mountain. Similar agglomerates occur along most of the north coast, the rock being in a few places scoriaceous or amygdaloidal; and they occur in huge fallen masses on the south side near the foot of the precipitous portion. The blocks in the agglomerate of the summit are usually six to eight inches across.

On the south-west side the massive rocks exposed are less basic with a specific gravity of 2.76 to 2.79. They are also more altered, the olivine being infrequent and the interstitial glass scanty. They differ besides in the parallel arrangement and in the length of the felspar-lathes (.18 mm.), which are on the average half as long again as those of the prevailing olivine basalts (.12 mm.). They are placed in a different order of these rocks and belong to genus 37 described on page 262.

Tuffs did not come frequently under my notice. At one part of the north coast the cliffs are formed of a palagonitic tuff-sandstone, effervescing with an acid, which is described on page 330. Although no organic remains are to be noticed, it is probably a submarine deposit.

On a spur on the south-west side, at an elevation of 600 feet,

there is exposed a hard red palagonitic tuff dipping away from the summit at an angle of 40° . It is mainly composed of the palagonitised *débris* of a vacuolar basic glass and incloses broken and entire crystals of plagioclase, augite, and olivine.

The augite crystals, which attain a length of five or six mm., project from the weathered surface and are easily detached, lying about in quantities on the ground in places. Although they are now imbedded in evidently a submarine tuff, these pyroxene crystals could only have been ejected as such from a subaerial vent; and it would therefore appear that they fell into the sea around the shores of a volcanic island in a state of activity. These crystals are often cracked and are as a rule not so perfect as those I have gathered from the slopes of Vesuvius, Stromboli, and Etna. They exhibit an unusual tabular form arising from the great development of the clinopinakoid at the expense of the orthopinakoid faces.

On the whole it may be inferred that the Naivaka volcano was submerged at the time of its origin, but that the eruptions continued after it began to show itself above the sea. In many of its features, especially in the character of the agglomerate that forms its upper portion, and in the palagonitic nature of the tuffs, Naivaka differs only from other elevated districts of the island, where organic remains occur, in the absence of such remains. Its form bears testimony to the extreme degradation we find in other districts, and the occurrence of foraminiferous tuffs high up the neighbouring slopes of Mount Sesaleka affords additional evidence of the original submergence of this district.

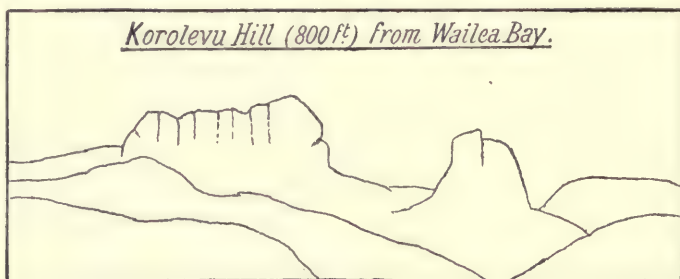
THE HILL OF KOROLEVU.¹—About three miles east of Mount Naivaka there rises to a height of 800 feet, about a mile inland from the shores of Wailea Bay, the singular flat-topped hill of Korolevu. It displays vertical cliff-faces, with a drop often of 200 or 300 feet, which have become so deeply furrowed or fluted by the eroding atmospheric agencies that they appear at a distance to be made of columnar basalt. The hill is, however, formed in mass of a compacted tuff or agglomerate tuff built up of materials of a hyalomelan basic glass that has undergone partial conversion into palagonite. In the upper thirds these rocks show no bedding, but in the lower slopes on the seaward side they are bedded and dip to the north away from the summit at an angle of 15° or 20° .

¹ This hill is figured in Wilkes' narrative under the name of Dillon's Rock (vol. 3, p. 235). This, however, is not the Dillon's Rock of his chart, where the name is given to a rock on the west side of the entrance to Wailea Bay.

The form of this hill is well shown in the sketch attached, and there is little doubt that we have here an old volcanic "neck," the remains of a submarine vent.

A specimen of the tuff from the summit is made up of compacted fragments, in size ranging up to one third of an inch, of a bottle-green vacuolar glass, which fuses readily in a lamp-flame and is not dissolved by hydrochloric acid. This glass is usually isotropic, but much of it is also palagonitic and feebly refractive, the vacuoles or steam-holes, which are often elongated, being in the last case filled with the same palagonitic material. Plagioclase crystals occur macroscopically in the glass; they are much eroded and contain numerous large inclusions both of the clear isotropic glass and of its palagonitised form.

About a third of a mile west of the Korolevu hill rises the hill of Ngangaturuturu, 450 feet high, which presents a precipitous cliff-



faced summit in which are exposed basic tuffs showing pyroxene crystals projecting from the weathered surface.

THE BOMB FORMATION OF NAVINGIRI.—A mile north-west of Korolevu Hill, where the coast road crosses a spur at the back of Navingiri, a very curious formation is exposed at an elevation somewhat under 200 feet above the sea. Here there are to appearance a number of large more or less spherical volcanic bombs, two to three feet across and formed of a semi-vitreous scoriaceous basalt, imbedded in a hyalomelan-tuff displaying the same microscopical characters as in the case of the tuff forming the adjacent hill of Korolevu.

The ash is light grey in colour and rather friable; but where in contact with the bombs it becomes darker and is hardened. The steam pores of the bombs are round and not elongated; and as is usual with these bodies they increase in size from the outside, where they are very small (1 millimetre and less), to the centre,

where they vary from two to five millimetres across. A vitreous border, about an inch in breadth, forms the outer shell of the bomb where it is in contact with the tuff. Some of the bombs are only two or three inches apart; and one of them shows evidence of fracture, fragments of the outer vitreous shell lying imbedded in disorder in the surrounding tuff.

Before entering into more detail it may be at once observed that the contiguity of some of the bombs to each other makes it at first difficult to view them as having been formed in the manner volcanic bombs are supposed to originate. Those who have seen the huge bombs lying scattered about on the summit of Vulcano in the Lipari Islands will appreciate the difficulty of imagining how these bombs can occur in such a close arrangement without having often shattered each other to fragments. However, Mr. Wittstock of Mbaulilai in a letter to me describes even larger bombs that came under his notice exposed on the surface in the Mbua district, their outer crust when broken looking "like the slag of a blast-furnace."

The bomb-rock is a semi-vitreous basaltic andesite. It displays microporphyritic plagioclase in a ground-mass formed mainly of a smoky, almost isotropic glass, in which numbers of felspar microliths (.1 mm.) are developed, the augite being but slightly differentiated. Scattered about in the glass are little irregular patches, or "lakelets," of residual magma composed of a yellowish feebly refractive material that I cannot distinguish from palagonite.

The ash, in which the bombs are imbedded, is a somewhat friable hyalomelan-tuff composed of fragments of basic glass often partially palagonitised, and usually 2 or 3 mm. in size. In it occur pumiceous lapilli of the same material up to 2 centimetres in diameter. The glass is markedly vacuolar, the cavities being either filled with gas or with alteration-products. The vacuoles are often drawn out into tubes, giving the glass a fibrillar appearance. The numerous plagioclase phenocrysts inclosed in the glass are much honeycombed and contain large inclosures of the glass, both altered and unchanged.

Although the line of contact is well defined in a hand-specimen, the two rocks cannot be separated along the junction. In a thin section, in which the union of the vitreous shell of the bomb with the ash is well shown, there is no defined line of demarcation, the non-vacuolar isotropic glass of the bomb being there broken up into fragments, with the interspaces filled with the partially palagonitised pumiceous ash. In the vitreous shell the felspar microliths are much less developed both in size and number than

in the central portion of the bomb. Numerous cracks communicating with the round steam-pores, which are much larger than the vacuoles of the ash-glass, are filled with the same yellowish magma-exudation referred to in the case of the rock forming the centre of the bomb. Through the cracks this palagonite-material has found its way into the steam-pores.

It would appear from the above that the bombs were but partially consolidated when they fell into the bed of ash. The tuff is somewhat "baked" where it is in contact with the bombs; and there is evidence of a collision between the bombs in the fragments of the vitreous shell imbedded in the ash. Although the ash itself contains no organic remains, there occur, not many hundred yards away and at an elevation 100 feet higher above the sea, foraminiferous tuffs of basic glass which are described below. There is no indication of a crateral cavity in this locality; whilst the ancient "neck" represented by Korolevu Hill is a mile away. These bombs most probably after being ejected from some sub-aerial vent fell into the sea around, on the floor of which much basic pumice-ash had been previously deposited. Such masses as they sank would lose most of their original momentum.

REMARKABLE SECTION NEAR KOROLEVU HILL.—Between the hills of Korolevu and Nganga-turuturu, at an elevation of about 300 feet above the sea, there is a singular exposure of tuffs horizontally stratified and forming a low escarpment or line of cliff about 15 feet high on the hill-side. These beds display the passage from basic tuffs below to relatively acid tuffs above, and they establish that in this locality the period of acid andesites followed that marked by the eruption of basalts and basaltic andesites. From their horizontal and undisturbed position, it may be inferred that these deposits began to be formed under the sea when the activity of the submarine basic vents was on the wane. In their composition and in the various degrees of coarseness of their materials, we can plainly discern the history of volcanic action in this locality.

A hard compacted palagonite-tuff makes up the lower half of the thickness of beds exposed, 15 feet in all. The greater portion of it has the uniform texture of a sedimentary rock, fine-grained below where the fragments are .1 to .3 mm. in size, and becoming coarser above where the larger measure 1 to 2 mm. It is composed of more or less angular fragments of a basic vacuolar isotropic glass, and of plagioclase and augite with much fine palagonitic *débris*. There is no effervescence with an acid; but in the upper part there

are a few casts of foraminifera of the "globigerina" type, as indicated in the thin sections. Above this lies a bed of a similar basic tuff, having however a banded appearance from the arrangement of materials of different degrees of coarseness, the finer being .1-.2 mm. in size, the coarser .4-8 mm. There is little or no carbonate of lime; but occasional tests of foraminifera of the type above mentioned occur in the slide. The basic tuffs here abruptly terminate. They represent the quiet deposition in water comparatively deep of the products of marine erosion, and of the finer ejectamenta of some distant subaerial vent.

Above the basic tuffs lie a series of tuffs, about 5 feet in thickness, and composed mainly of the debris of acid andesitic rocks of the hornblende-andesite type, such as occur in the Ndrandramea district. They mark a period of active eruption on the part of some neighbouring acid andesitic vent in this neighbourhood, which the subsequent explorer may be able to identify with some volcanic "neck."

These tuffs are composed partly of fragments of a hemi-crystalline hornblende-andesite and partly of crystals, broken and entire, of plagioclase, hornblende, rhombic pyroxene, and augite. The plagioclase is tabular, zoned, and glassy, and gives extinctions of oligoclase-andesine (6 to 12°). The hornblende is bottle green, markedly pleochroic, and gives extinctions up to 14°. The rhombic pyroxene has the characters described on page 301, in the case of the Ndrandramea rocks. The augite is less frequent, but the two pyroxenes are sometimes associated as intergrowths.

These acid tuffs do not effervesce with an acid, nor can any tests of foraminifera be observed in them; but since these organisms are represented in the basic tuffs below, it is highly probable that the whole series of these horizontal beds is submarine. The first or lowest bed of the acid tuffs indicates a somewhat violent volcanic outbreak in this neighbourhood, following the deposition of the basic tuffs. It is composed of loosely compacted subangular fragments, 1 to 3 millimetres in size, in which the macroscopic prisms of the rhombic pyroxene are especially frequent. It passes upward without interruption into a regularly grained sandstone formed of rounded and subangular fragments measuring .3 to .7 mm. across. Above this lies a quite distinct bed, a few inches thick, of a fine compact clay rock, where the mineral fragments measure only .05 to .12 mm. in diameter, hornblende being well represented, although the rhombic pyroxene is very scanty. Up to this time these beds of acid tuffs indicate a gradual defervescence

of the volcanic activity that began with some violence, as shown by the characters of the lowest bed. Now another outbreak occurred, and overlying the clay-like bed we find a coarse tuff made up of fragments 2 to 5 millimetres across, and approaching in texture and appearance a subaerial tuff, but in other respects similar to those below it. It is the last and uppermost of this series of acid tuffs, and with it terminates an interesting record of the past in this region, the chief features of which may thus be summarised.

A prolonged period of quiet deposition of submarine basic tuffs, the products partly of marine erosion and partly of distant eruptions, was abruptly followed by the outbreak of a neighbouring vent during which tuffs formed of the debris of acid andesites were deposited. The gradual decrease in the degree of activity is plainly shown in the gradual diminution in size of these tuffs, until they acquire the fineness of a clay. Then another burst of activity from the same vent or vents occurred, and the record ends. Since that time there has been apparently an upheaval to an elevation of 300 feet above the sea. As, however, the beds are quite undisturbed, the emergence may have been due to the lowering of the sea-level, a subject which is discussed in Chapter XXVII.

COAST BETWEEN WAILEA BAY AND LEKUTU.—The hills here often approach the coast, their spurs running down to the beach. In the low range, 250 to 300 feet high, east of Wailea Bay, are exposed palagonite-tuffs dipping gently north-east and composed of fragments of a vacuolar basic glass, more or less palagonitised, and of minerals (plagioclase, etc.) not exceeding 2 mm. in size. These deposits are apparently non-calcareous and show no organic remains.

Farther along the coast towards Nativi basic tuffs and agglomerates appear at the surface; but the underlying rock, exposed in position in the stream-courses and prevailing along much of the sea-border to Nativi and a mile or so beyond, is a vesicular semi-ophitic basaltic andesite with coarse doleritic texture and containing much interstitial smoky glass. (It belongs to the non-porphyritic group of genus 9 of the augite-andesites described on page 273.) Such rocks evidently represent ancient flows. They give place as one proceeds east to porphyritic semi-ophitic doleritic rocks of the same genus and to semi-vitreous basic rocks. About half a mile west of Nukunase a vesicular doleritic basaltic andesite forms a spur protruding at the coast. It is semi-ophitic and contains in the smoky glass of the groundmass little irregular cavities filled with a yellowish residual magma like palagonite in character. (It is

referred to genus 12 of the augite-andesites, described on page 275.) A few paces west of this spur a vertical dyke, 20 feet wide and trending N.W. and S.E., appears on the beach. It is formed of a bluish scoriaceous basaltic andesite containing much glass in the groundmass and showing imperfectly developed felspar lathes. It is included in genus 4 of the augite-andesites described on page 270.

A little east of the spur there is another dyke apparently vertical and formed of a vesicular rather than a scoriaceous basaltic andesite referred to genus 1 of the augite-andesites (page 267). It differs from the rock of the previous dyke in the presence of small plagioclase phenocrysts which contain abundant magma-inclusions; but it resembles it in the characters of the groundmass. This dyke is about 40 feet in thickness and trends N.E. and S.W.

It may be inferred from the foregoing remarks that there was at one time a volcanic vent in the district west of Nukunase. The lines representing the trend of the two dykes above noticed would if extended meet at a common focus a little way inland. The rocks of the dykes differ conspicuously from the prevailing doleritic rocks that form, as before remarked, the ancient flows, the average length of the felspar-lathes in the former being .1-.2 mm., in the latter .3-.4 mm. Both, however, belong probably to the same vent of which now the exact situation would not be easy to discover, on account of the re-shaping of the surface through the denuding agencies.

MOUNT KOROMA.—The highest peak of the hills lying inland between Wailea Bay and Lekutu is named Koroma and attains a height of 1,384 feet. I did not ascend its slopes higher than 900 feet, and approached it from the Mbua or south side. Extensive plains, covered with the usual "talasinga" vegetation, reach inland from the shores of Mbua Bay to the foot of this range without attaining a greater elevation than 100 feet. This low district is drained by the Mbua river and its tributaries, the rock usually exposed at its surface being a decomposing porphyritic basaltic andesite. It is again referred to on page 56 in connection with the low-lying level region of this portion of the island of which it in fact forms a part.

A basic non-calcareous fine-grained tuff-sandstone is exposed in a stream at the foot of the south slope of Mount Koroma. Whilst crossing some low wooded outlying hills in this locality, I came suddenly upon what seemed like a desert in miniature, quite bare of vegetation and occupying an area of some acres. Here a porphyritic basic rock, from some cause unknown to me, has decomposed in the mass to a depth of 20 feet and more; and

the result is a surface of white crumbling rock scored deeply by the rains and carved out by the denuding forces into miniature hills and dales. It is not improbable that a small crater in its last solfatara-stage once existed here; but the whitened disintegrated rocks alone remain, and we can now only hazard a conjecture as to the cause.

I found a variety of basic rocks exposed on the hill slopes up to 900 feet. The most frequent of the deeper-seated rocks which occurred in mass at this elevation, and as large blocks on the lower levels, is a dark grey rather altered hypersthene-augite-andesite, referred to genus 1 of that sub-class as described on page 286. The specific gravity is 2.73, whilst the groundmass displays a little greenish altered glass. Another of the deeper rocks, exposed 500 feet up the slopes, is placed in the same sub-class, augite and rhombic pyroxene being porphyritically developed, separately and as intergrowths. The groundmass displays short stout feldspars, augite, and a little altered glass. The rock is therefore referred to the orthophyric order described on page 290. Spec. grav. 2.78.

Evidence of more recent surface lava-flows here exists. In one place I came upon such a bed 12 feet thick, compact in its upper half and slaggy or scoriaceous in its lower half. The rock is an aphanitic augite-andesite (spec. grav. 2.77) and belongs to species B, genus 16, of the augite-andesites, as described on page 281. Its groundmass displays feldspar-lathes in flow-arrangement with a little interstitial glass. Slaggy lava is not uncommon on these slopes. One specimen beside me is a semi-vitreous form of the deeper hypersthene-augite-andesites of this range.

There appears to be better evidence of sub-aerial lava-flows on the lower slopes of Mount Koroma than I found in any other part of the island. It should have been before remarked that one of these flows lies upon a bed of a hard reddish compact tuff, which appears in the thin section as an altered palagonite-tuff, containing fragments of minerals including both rhombic and monoclinic pyroxene, but showing neither lime nor organic remains. The larger fragments are 2 mm. in size. It seems likely that this flow ran into the sea during the emergence of this part of the island.

The prevalence of rocks of the hypersthene-augite-andesite type in Mount Koroma distinguishes this range from the surrounding regions of olivine-basalts and basaltic andesites. This district is well worth a detailed examination, and perhaps the remains of a crateral cavity may yet be found.

THE COAST BETWEEN NAIVAKA AND KORO-NI-SOLO AT THE FOOT OF THE NORTH SLOPE OF THE SESALEKA RANGE.—Basaltic andesites, and olivine-basalts of the Naivaka type occur on this coast. A rock of more acid character, light grey and much altered, is exposed at the surface where the track crosses the headland projecting into Ruku-ruku Bay. It is one of the propylites referred to in my description of the second genus of the augite-andesites (p. 269). The feldspars of the groundmass give the small extinctions of oligoclase; and in this respect it differs from the other augite-andesites. Besides the altered plagioclase phenocrysts there is much microporphyritic augite but slightly changed. Calcitic and other alteration products occur in the interstitial glass.

MOUNT SESALEKA.—This is the name of the highest peak, 1,370 feet, of a remarkable ridge-shaped range, which is very precipitous on the east and north-east sides, where there is a sheer drop apparently of 500 or 600 feet, whilst on the other sides the slope is more gradual, especially on the north where there is a gentle descent to the sea. The actual summit is bare, rocky, and narrow. There is a curious native legend relating to a pond on the top of this hill. From what Mr. Wittstock tells me, it seems probable that there is a spring near the summit. Close to the top are the remains of an old "koro-ni-valu" or war-town; whilst numbers of shells of species of *Cardium*, *Cypræa*, and *Strombus*, such as would be used for food, lie about. Many years ago there was a prolonged siege of this stronghold, which is referred to here as indicating that the defenders had some independent water-supply.

In ascending from Koro-vatu on the west side basic agglomerates and agglomerate-tuffs were found exposed as far as half-way up. In the upper half occurred at first fine-grained calcareous tuffs, bedded and dipping gently down the slope, composed of palagonite-debris, mineral fragments and calcitic material and displaying a few macroscopic tests of foraminifera. These tuffs became non-calcareous and coarser as one approached the summit. A specimen obtained from the top is coarse-grained, being composed of fragments of basic glass, usually palagonitised, much augite, a little plagioclase and fresh olivine, but no tests of foraminifera, the size of the fragments being usually .5–1.5 mm. Massive rocks were rarely exposed on this side; but half-way up in a stream course I came upon an exposure of a porphyritic olivine-basalt containing a fair amount of devitrified interstitial glass. Its

specific gravity is 2·85 and it is referred to genus 25 of the olivine basalts (page 259). I descended by a gentle slope to the north, coarse basic tuffs and agglomerates containing amygdaloidal fragments being displayed on the surface. In a stream at the foot, close to Koro-ni-solo, were blocks of a heavy compact olivine-basalt with specific gravity 2·96.

DISTRICT BETWEEN MOUNT SESALEKA, THOMBO-THOMBO POINT, AND VATU-KAROKARO HILL.—This is a broken country with several abruptly rising lesser hills. Starting from Koro-vatu and crossing the Thombo-thombo promontory, I reached the coast of Mbua Bay near Navunievu. Basic tuffs and agglomerates prevailed on the way, the last containing blocks of a scoriaceous basaltic lava bearing olivine. The massive rocks exposed belong in some cases to genus 13 of the olivine-basalts as described on page 256, being dark grey and having a specific gravity of 2·88, and in other cases to genus 16, species B, of the augite-andesites when they are lighter in colour and have a specific gravity of 2·77. In both cases the interstitial glass is scanty.

I ascended Vatui, one of the numerous small hills of the district. It is 450 feet high and is capped by a bare mass of tuff-agglomerate, 40 to 50 feet high and containing fragments of vesicular basic lava. This mass is pierced by a dyke, 18 inches thick, which is inclined to the N.NE. at a high angle of 60 or 65 degrees with the horizon. This dyke is composed of a compact olivine-basalt which is remarkable for the prevalence of small augite prisms in the groundmass. It is described on page 265 under genus 44 of the olivine-basalts. Hand-specimens are magnetic and display polarity, which is due, as pointed out in Chapter XXVI., to the exposed situation of the peak.

Vatui in its characters is evidently typical of the other lesser hills around, which, as viewed from below, possess bare tops and precipitous declivities of the same formation. All the hills in the district including Sesaleka are capped by these basic tuffs and tuff-agglomerates; and doubtless as in the case of Sesaleka these deposits are all submarine. This is true also of Vatu-karokaro, a hill 600 feet high, overlooking Mbua Bay and about two miles east of Sesaleka. In the lower part of this hill is exposed a dark compact basaltic andesite, referred to genus 13, species B, of the augite-andesites (sp. gr. 2·83), whilst blocks of a black olivine-basalt (sp. gr. 2·91) occur in the agglomerate of the summit. These hills may all be regarded as "volcanic necks" or the stumps of volcanic cones, probably submarine.

THE DIVIDING RIDGE BETWEEN THE MBUA AND LEKUTU PLAINS.—A level rolling "talasinga" district intervenes between Mbua Bay and the dividing ridge. The upper part of this ridge, which attains a height of about 500 feet above the sea, is composed of a hard grey sandstone-like tuff, effervescing feebly with an acid, which on examination proves to be formed in great part of fragments, .07-.1 mm. in size, of a dark basic glass occasionally vacuolar. The rest of the deposit consists of similar-sized fragments of plagioclase and other minerals, and includes also a few tests of foraminifera of the "Globigerina" type.

The mass of the ridge, however, is composed of coarse tuffs and agglomerates of a different kind which have been covered over by the foraminiferous deposit just described. Thus there are exposed on the lower slopes, tuffs and agglomerates of a basic pitchstone formed of a brown glass containing a few felspar and pyroxene microliths. In the tuff the fragments are three to six mm. in size and show evidence of crushing *in situ*, the interstices being filled with debris of the same material more or less palagonitised,¹ but there is no carbonate of lime. Large masses of an agglomerate made up of blocks of an acid andesite occur higher up the slopes. The component rock belongs to an unusual type of hypersthene-andesite, specially noticed on page 297.

The interesting feature in this ridge lies in the testimony it affords that the extensive Mbua and Ndama basaltic plains, on which I was unable to discover any submarine deposits, were at one time submerged.

THE MBUA AND NDAMA PLAINS.—These rolling plains are a striking feature in the western end of Vanua Levu. They have an arid barren look, are clothed with a scanty and peculiar vegetation, possess a dry crumbling soil often deeply stained by iron oxide, are traversed by rivers without tributaries descending from the wooded uplands of the interior, and in fact have well earned the name given to them by the natives of "talasinga" or sun-burnt land. Both Seemann and Horne have remarked on the South Australian aspect of these regions, which are characteristic of the lee and drier sides of the larger islands of the group. Covered for the most part with grass, ferns and reeds, these low-lying districts are dotted here and there with Casuarinas, Pandanus trees and Cycads, whilst such other trees and shrubs as *Acacia Richii* and *Dodonæa viscosa*, add to the variety and peculiarity of the vegetation. The origin of these "talasinga" districts is discussed in the last chapter.

¹ See remarks on "crush-tuffs" on p. 334.

The Mbua and Ndama plains form a continuous region extending three to five miles inland to the foot of the great mountain of Seatura, to the watershed between Mbua and Lekutu, and to the base of Mount Koroma ; whilst it reaches along the sea border from the vicinity of Navunievu about four miles west of the Mbua River to beyond Seatovo a few miles south of the Ndama River. Their extent is defined in a general sense by the 300 feet contour line in the map. Their elevation, however, above the sea does not generally exceed 200 feet and is usually only 50 or 100 feet ; but at the foot of Seatura they rise to between 300 and 400 feet. Whilst on the one side these plains form a continuation of the lower slopes of the great Seatura mountain, on the other side they are extended under the sea as the broad submarine platform, the edge of which, as defined by the 100-fathom line, lies eight to ten miles off the coast. It is pointed out on page 372 that this continuity of surface, both *supra*-marine and submarine, extends probably to the geological structure and that the submarine platform represents the extension under the sea of the basaltic flows of the plains.

The whole region of the plains is occupied by olivine-basalts and basaltic andesites, such as are found on the neighbouring lower slopes of the Seatura mountain. They are as a rule much decomposed, even at a depth of several feet below the surface. Typically, they are neither vesicular nor scoriaceous, and in this respect they possess the character of submarine lava-flows. The rolling surface of the plain is varied occasionally by small " rises " or hillocks marking apparently some secondary cone, of which the much degraded " wreck " alone remains. Here and there fragments of limonite, approaching hæmatite in its compact texture, lie in profusion on the soil, representing doubtless small swamps long since dried up, some of which still occur in the hollows of the plain. Mingled with these fragments are often pieces of siliceous rocks and concretions, such as are found in the other " talasinga " districts of the island, the description of which is given on pages 128, 132, &c.

I will now refer more in detail to some of the points alluded to in this short description of these plains. With reference first to the compact limonite, it should be remarked that it occurs on the surface either as fragments of hollow nodules two or three inches across, or as portions of flat " cakes " half to one inch thick. It is especially abundant in the district lying a mile or two on either side of the Navutua stream-course between Ndama and Mbua. Here the subsoil is charged with ferruginous matter, and the water

of the series of stagnant pools in the bed of the stream is stained blood-red by iron-oxide, a circumstance that has naturally given rise to native legends of a corresponding hue. These fragments of iron ore, which lie between 100 and 150 feet above the sea, represent the final stage of a process which is now no doubt in operation on the bottom of the neighbouring pools and small swamps. Their presence on the surface goes to indicate that this open country has been for ages a land-surface free from forest, as it is in our own time.

In a similar manner, the extensive disintegration of the basaltic rocks that form these plains affords evidence of the great antiquity of these "talasinga" plains in their present unforested condition. The extent to which these rocks have weathered downwards is very remarkable. Between Ndama and Mbua they are decomposed to a depth often of eight or ten feet below the surface. This is well exhibited in the sides of deep channels excavated by the torrents during the rains. Here the spheroidal structure is well brought out in the disintegrating mass, all stages being displayed in the formation of the boulders that are scattered all over these plains.

In one locality, near the lower course of the Ndama river, a thickness of 25 feet of decomposed rock was exposed in a cliff-face. In this case the rock was a porphyritic basaltic andesite, the disintegrating process having affected the whole thickness of the large spheroidal masses with the exception of a hard central nucleus of the size of the fist. In one of these nuclei by my side it is apparent that during the extension of the weathering process the phenocrysts of glassy plagioclase become opaque long before the groundmass is affected. In this specimen the stage of disintegration as affecting the felspar phenocrysts is at least one and a half inches in advance of that affecting the groundmass.

This great disintegration of the basaltic rocks, which as pointed out on page 64 is also in progress on the slopes of the adjacent spurs of Mount Seatura, is more characteristic of the porphyritic basaltic andesites than of the olivine-basalts. It is to the spheroidal weathering that we must look for an explanation of the rounded boulders so frequent in these districts. It may also be inferred that the soil produced from this extensive decomposition of the rocks is often very deep. At the Wesleyan Mission Station at Mbua, on level ground nearly a hundred feet above the river, a well has been sunk to a depth of 20 feet in soil of this description ; and away to the westward a similar thickness of soil produced by the same cause is in places to be observed.

Coming to the characters of the basaltic rocks of the Mbua and Ndama plains, it may be remarked that the prevailing rocks are the porphyritic basaltic andesites, having a specific gravity of 2·77 to 2·81, which are in most cases to be referred to genus 13 (porphyritic sub-genus) of the augite-andesites described on page 278. They possess large phenocrysts of plagioclase and but little interstitial glass. The other rocks are olivine-basalts with specific gravity 2·88 to 2·90 and showing only a few small plagioclase-phenocrysts. They display a little residual glass and belong for the most part to genus 37 of the olivine basalts described on page 262. In both these basaltic rocks the felspar-lathes are in flow-arrangement; but in the basaltic andesites they average ·11 mm. in length, whilst in the olivine-basalts they average ·18 mm.

The low mound-like "rises" in these plains, to which previous reference has been made, are not usually elevated more than 50 feet above the general surface. One of these hillocks that lies near the track from Mbua to Navunievu, about two miles from the Wesleyan Station, is composed of a remarkable semi-vitreous pyroxene-andesite passing upward into a rubbly rock of the same nature. The rock of this old volcanic neck is of an unusual type and is referred to the prismatic order of the hypersthene-augite andesites described on page 289. Both the felspar and pyroxene prisms of the groundmass are in flow-arrangement. One of these mounds near the Mbua Wesleyan Station is apparently formed of the decomposing basaltic andesite of the district. On its surface are fragments of earthy limonite and siliceous rocks.

The rarity of submarine tuffs and clays on these plains is somewhat singular; but in the occurrence of foraminiferous tuffs high up the slopes of Sesaleka and on the crest of the Mbua-Lekutu dividing ridge we have evidence of the original submergence of all these lower regions. It is probable enough that the ages of exposure that have since witnessed the reduction of the solid basaltic rock to a crumbling mass several feet in depth were more than sufficient for the stripping off of most of the overlying submarine deposits. Such deposits are, however, common on the surface of the extensive "talasinga" plains that constitute much of the north side of the island.

THE SHELL-BED OF THE MBUA RIVER.—Rather curious evidence of an emergence of a few feet and of a considerable advance of the delta of the Mbua river in comparatively recent times is afforded by a bed of marine shells exposed in the right bank of this river, about 200 yards below the boat-shed of the

Wesleyan Mission Station and about two miles in a straight line from the sea. This bed, which is about a foot in thickness, is exposed for a distance of 70 or 80 yards. It slopes gradually seaward as one descends the river, being raised two or two and a half feet at its upper end above the river level at low tide, whilst at its lower end it is at about the water-level. The river-bank is here 15 or 16 feet high, and is composed in its upper half of a fine gravel of volcanic rocks mixed with earth, which below passes abruptly into a friable non-calcareous black mud-rock (not bedded and looking like consolidated swamp mud), in which the layer of shells is contained. These shells are, therefore, covered by deposits, 13 or 14 feet in thickness, of which the upper eight feet are formed of gravel and earth, and the rest of mud-rock. They are evidently gathered together on the slope of an old mud-flat.

The shells are all large marine bivalves, belonging to the genera *Ostræa*, *Meleagrina*, *Cardium*, *Arca*, &c., no freshwater shells occurring. They are often much decayed and have lost the ligaments. The valves are generally separate ; but in some cases they are still in apposition, the cavity being then filled with the same black mud in which the shells are embedded. They lie about in all positions, some vertical, some horizontal, and are often piled on each other. In some cases large borers have perforated one or both of the valves ; and here and there valves may be noticed with smaller oyster-shells attached to the inner surface. No vegetable remains were discovered with the exception of a single "stone" of the fruit of the Sea tree,¹ which is common in these islands, its empty almost indestructible stones occurring frequently in the drift stranded at the mouths of rivers.

At first sight one would look to human agency for the explanation of this shell-bed ; but many of its features are inconsistent with such a view. If the shells had been originally collected by the aborigines for food, the absence of those of marine univalves of the genera *Turbo*, *Strombus*, *Cypræa*, &c., such as are much appreciated as food by natives, is inexplicable. The extent of the bed and its uniform thickness are characters that give no support to such an explanation. It represents, as I apprehend, an ancient shell-bank formed on a muddy bottom in comparatively shallow water near the mouth of a river. Since that time the Mbuia River has cut through its old deposits, and the margin of its delta is now two miles to seaward, the intervening new land being formed of extensive mangrove-swamps in its lower part, whilst nearer the

¹ Species not identified.

shell-bed there is much level land raised a few feet above the sea, on which the native town and different villages now stand. The amount of emergence here indicated since the time when this bank of shells was forming under the sea does not probably exceed a couple of fathoms.

LEKUMBI POINT.—This singular long and low promontory is between three and three-and-a-half miles in length and rather less than a mile in average width. It is monopolised by mangroves, except at the extremity where the swampy ground passes into the dry sandy soil occupied by the characteristic vegetation of coral beaches. This terminal portion, which is about a third of a mile in length and raised a couple of feet above high-water mark, was originally a reef-islet. The outer third of the cape, however, is cut off from the remainder by a narrow winding passage in the mangroves, which being 25 or 30 feet wide can be traversed by boats at and near high-water, and is often used to shorten the journey down the coast. The flowing tide rushes in at both entrances, and when the tide is ebbing it finds its way out at both exits, the passage presenting the readiest way of the filling and emptying of the interior swamps with the flow and ebb of the tide.

Before explaining the origin of this low tongue-shaped promontory of Lekumbi, it should be observed that it lies on a long projecting patch of coral reef which is continuous with the neighbouring shore-reefs. Depths of seven and eight fathoms are found off the sides and of 11 and 12 fathoms off the end of the reef-patch. This reef in its turn must have been built up on a submarine bank protruding from the coast. Such a bank may have originally been produced by the deposits brought down by the Ndama River which finds an exit through the mangroves near the base of the cape. With the exception, however, of the Lekutu River, none of the other Vanua Levu rivers have given rise to such tongues of land at their mouths. I am more inclined to hold that the submarine shoal, which underlies the present low cape of Lekumbi, indicates an old lava-flow from the great crateral valley of Seatura, opposite the mouth of which it lies. Traces of such flows are still to be found in that locality.

CHAPTER V

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE SEATURA MOUNTAIN.—In my description of the profile of this part of Vanua Levu, reference has already been made (p. 3) to the great mass of this mountain which occupies five-sixths of the breadth of the island. Viewed from seaward it looks like a huge table-topped mountain-ridge, and as such it is represented in the Admiralty charts; but when its true contours are distinguished it appears, when defined by the 300-foot level in the map, as a somewhat rounded mass, measuring 12 miles in length and 10 miles in breadth and attaining a maximum height of 2,812 feet. Seen from the deck of a passing ship it displays more or less regular volcanic slopes, especially on the east, where there is a gradual descent at an angle of 3 or 4 degrees for some 10 miles, and on the north towards the Lekutu lowlands. It also shows a fairly regular descent towards Mbua Bay on the west. (See profile, p. 62.)

On the west side, however, there is a great gap in the mountain-mass (the Ndriti Gap), marking, as I hold, an old crateral cavity of large dimensions, and now occupied by the Ndama River and its tributaries.

The adjacent Seatovo Range to the southward obscures the profile of the mountain on the south; and it is in fact not at all easy for this reason to get a view with all the slopes displayed. It is only at times, when viewed in its complete mass with uninterrupted outlines, as from off the mouth of the Ndreketi River to the north-east, or when the symmetry of its long eastern slope is observed from Wainunu Bay that Seatura displays itself as a gentle-sloped mountain-mass of the Mauna Loa type. Dense forest

Profile and Geological Section of the western end of Vanua Levu from the Wainunu estuary across the summit of the basaltic mountain of Seatura to the edge of the submarine platform off the Ndama coast as limited by the 100-fathom line.



clothes the greater part of it, except on the north and north-west, where it lies within the limits of the scantily vegetated "talasinga" region.

The slopes of this mountain are deeply furrowed by river-valleys which radiate like the spokes of a wheel from its central elevated mass. Down its northern slopes flow the Lekutu River and its tributaries and the principal tributaries of the Sarawanga River. The large western affluents of the Wainunu River descend from its eastern side, whilst the Korolevu, Tongalevu, and other small rivers flow south into Wainunu Bay, and the Ndama River drains its western slopes. In all these cases, excepting that of the Ndama River, the rivers have worn deep valleys into the mountain-mass, valleys of denudation that represent the work of ages. That of the Lekutu is a deep cut almost into the heart of the mountain; at Nandrora in this valley, which lies 6 to 7 miles inland and 800 feet above the sea, the hills rise steeply on either side of the river to an elevation of 1,100 and 1,200 feet and more. Some of the large tributaries of the Sarawanga and the Wainunu flow through gorge-like valleys 200 to 300 feet in depth. On the western slopes north of the Ndama river, the mountain-side presents an alternating series of lofty spurs and deep broad valleys. In fact, all around Seatura its slopes are deeply furrowed through the denudation and erosion of ages.

The rocks of this ancient volcanic mountain are almost all of the massive basic type, and except at the mouth of the Ndriti Gap hardly ever display a scoriaceous character. It is also noteworthy that no detrital rock, whether agglomerate, tuff, or tuff-clay came under my observation. The rocks exposed on the surface are mostly blackish brown olivine-basalts and porphyritic basaltic andesites, the former much prevailing. In the northern portion, however, grey olivine basalts of a different type occur. In the great crateral hollow, which I have named the Ndriti Gap, are displayed numerous dykes formed of highly altered basaltic rocks that may be classed among the propylites.

The dense forest that clothes the greater part of this mountain offers many serious hindrances to geological exploration. Except in the northern portion, views of the surroundings are very limited, and one has often to rely mainly on the aneroid and the compass to obtain correct ideas of the contours and general configuration. During most of the time spent in the southern part of the mountain, my work was greatly impeded by heavy rains, and from this cause and from the frequent necessity of following up the stream-courses and of crossing rivers in flood, I was usually wet through all the day.

(a) *The Eastern Slopes of Seatura.*—The basaltic flows, of which this mountain is principally composed, are best observed on the eastern side where the original volcanic slopes are preserved. Although the rivers have worn such deep valleys into the mountain sides, it is however not often that any great exposure of rock occurs, on account of the dense forest-growth over much of this region. It is only occasionally that the columnar structure of these old basaltic flows is displayed. It is especially well exhibited in the face of a waterfall, distant about two miles in a straight line from Tembenindio and elevated about 700 feet above the sea. Here there is an exposure to the extent of 25 feet of huge basaltic vertical columns, four to five feet across, and pentagonal in form. The rock is a blackish basalt with scanty olivine and a specific gravity of 2·87. It is referred to genus 25 of the olivine-basalts which is described on page 259. Micro-phenocrysts of plagioclase and a few of augite occur, the olivine being mostly replaced by pseudomorphs. The felspar-lathes of the groundmass average 18 mm. in length, and there is a little brown opaque interstitial glass. Boulders and fragments of a closely similar basalt, with a specific gravity of 2·9, lie about on the surface in this region. The Seatura slopes here abut on the plateau of Na Savu, formed largely of volcanic agglomerates, to be subsequently described.

On the south-eastern slopes of the mountain between Ndawathumi (inland) and Korolevu (at the coast), somewhat similar basalts with scanty olivine are exposed (sp. gr. 2·86—2·91). Some of them show the felspar-lathes of the groundmass arranged in a plexus (genus 25), whilst others exhibit flow-structure (genus 37), the average length of the lathes varying in different localities between ·15 and ·21 mm. All display scanty residual glass. On the shores of Wainunu Bay between the Wainunu and Korolevu rivers occur porphyritic basaltic andesites with a considerable amount of glass in the groundmass. There is exposed on the right side of the mouth of the last-named river a highly basic variety of olivine-basalt with a specific gravity of 3·07. It is referred to genus 15 (described on page 258), which includes the most basic rocks in my collection. There are in this rock no plagioclase phenocrysts and the felspar-lathes of the groundmass are relatively infrequent, whilst olivine and augite occur in abundance. There is little or no residual glass. In the district of Tongalevu blackish olivine-basalts and basaltic andesites of the usual character are found. In the Na Suva range, which lies two miles inland from the shores of Nasawana Bay and forms the southerly extension of the mountain, a somewhat compact variety of olivine-basalt (sp. gr. 2·92) prevails up to the summit, 1,550 feet above the sea. It is included in genus 37 of the olivine-basalts. In the length of the felspar-lathes (·15 mm.) it belongs to the Seatuta type of these dark basalts.

(b) *The Western Slopes of Seatuta*.—Here overlooking the plains north of the Ndama River the same olivine-basalts and porphyritic basaltic andesites occur. The vegetation is of the scanty "talasinga" character, and since there is little or no soil-cap the disintegration of the rocks has been very great, often extending to a depth of 10 or 12 feet. It is remarkable that this disintegration is most marked in the "talasinga" and similar scantily wooded districts of the mountain. On the densely wooded eastern and southern sides where there is a thick soil-cap, it is by no means so evident. Here on the western slopes have been carved out deep broad valleys and lofty spurs, the last in their turn furrowed on their flanks, without any apparent sufficient cause. The shallow streams at the bottom of the valleys appear quite incompetent to produce such great erosion; and doubtless these results are partly due to the action on the crumbling rock-surface of temporary torrents formed during the rains.

(c) *The Northern Slopes of Seatuta*.—Here within the scantily

vegetated "talasinga" region the conformation of the land is well displayed. Broad, deep and nearly parallel valleys, separated by level-topped spurs and occupied by the Lekutu and its tributaries, score the mountain's slopes. The prevailing rocks are blackish-brown olivine-basalts and porphyritic basaltic andesites, such as occur around the other parts of Seatura; but grey olivine-basalts also occur, possessing opaque plagioclase-phenocrysts and looking like porphyrites. They are essentially holocrystalline and are probably more deeply situated than the other basaltic rocks. They are referred to genera 26 and 38 described on pages 261, 263, and have a specific gravity of 2.75—2.83. Dark doleritic basalts distinct from all the others are exposed in places.

A good idea of this region may be obtained by following the road westward from Tavua on the head-waters of the Sarawanga River to Wailevu on the westernmost tributary of the Lekutu River, a distance of about 6 miles. Leaving Tavua one at once begins to ascend and cross the long spur that descends from Seatura and divides the valleys of these two river-systems. On its slopes are exposed much decomposed blackish basalts possessing scanty olivine and showing large porphyritic crystals of plagioclase. They have a specific gravity of 2.84 and are assigned to the porphyritic sub-genus of genus 25 (page 259). At the summit, 800 feet above the sea, occur blocks of a grey holocrystalline basalt with scanty olivine and semi-opaque plagioclase-phenocrysts referred to genus 26 and having a specific gravity of 2.76. It appears to form the axis of the spur. Descending to the main Lekutu River, just below Kavula, where the elevation is about 300 feet above the sea, one observes exposed in mass in the river-bed a dark semi-ophitic doleritic basalt similar to the doleritic rocks without olivine prevailing on the coast between Wailea Bay and Lekutu (see page 50), but differing in the absence of felspar-phenocrysts. It displays a considerable amount of opaque interstitial glass and is assigned to genus 12 of the augite-andesites (page 275). The specific gravity is 2.78, but there are a few minute irregular cavities in its substance.

On leaving Kavula one crosses another of the Seatura spurs at a level of 650 feet, descending then into a smaller river-valley occupied by a tributary of the Lekutu, on the banks of which lies the village of Nawai, 350 feet above the sea. Then another spur is crossed at an elevation of 450 feet and the descent is made into the valley of the Wailevu tributary of the Lekutu. Crossing the valley, which at the town of Wailevu is elevated 300 feet, one rises to a height

of 700 feet and then descends into the Mbua plains. These three almost parallel valleys of the Lekutu and its two tributaries are worthy of a detailed examination.

The rocks on the surface between Kavula and Wailevu vary in character. Nearer Kavula there appears a blackish compact olivine-basalt (spec. grav. 2·88), showing a little microporphyritic plagioclase and belonging to genus 37 of the olivine rocks. Further on is exposed one of the holocrystalline grey olivine-basalts with porphyritic plagioclase-phenocrysts and specific gravity 2·83. It belongs to the type described in genus 38 of the rocks on page 263. Nearer Wailevu there occurs a blackish porphyritic basalt with scanty olivine and specific gravity 2·81. It contains but little residual glass and is referred to the porphyritic sub-genus of genus 25. In some cliffs at the river-side close to Wailevu, there is displayed a semi-vitreous basaltic andesite, showing large porphyritic plagioclase crystals, 3 to 8 mm. Its low specific gravity (2·68) is to be attributed to the large amount of glass in the groundmass. There is a loose mesh-work of felspar-lathes, but the augite is not differentiated. Westward of Wailevu commence the decomposing basaltic rocks of the Mbua plains.

(d) *Traverse of the Northern Part of the Summit of Seatura from Kavula South-West to Narawai.*—The track first lay up the picturesque valley of the Lekutu River to Nandrora, 2½ miles distant and 800 feet above the sea. On the way blackish basaltic rocks of the prevailing Seatura type, with or without scanty olivine, were displayed often in a decomposing condition. At one place a characteristic grey olivine-basalt, showing opaque porphyritic plagioclase (sp. gr. 2·87), and looking like a porphyrite, was exposed. On account of the abundance of the olivine, it is placed in genus 2 of the olivine-rocks. After Nandrora the path lay up the steep mountain-side to a height of 1,500 feet: and afterwards across the summit of the northern part of Seatura, which is here about two miles in breadth. This elevated region is well wooded with here and there a patch of "talasinga" land; but it is by no means level, its elevation varying between 1,400 and 1,800 feet, and it soon became evident that we were crossing the heads of valleys, sometimes 200 or 300 feet in depth, that could only have been excavated by the torrential rains. These streamless valleys afford another indication of the denudation to which this ancient mountain has been subjected.

The rocks prevailing in this elevated northern portion of Seatura, at heights of 1,500 to 1,800 feet above the sea, are: (a) blackish

basalts with scanty olivine, a little interstitial glass, and belonging to the porphyritic and non-porphyritic sub-genera of genus 25 of the olivine-rocks: (*b*) grey olivine-basalts with porphyritic opaque plagioclase, containing but little residual glass, but varying greatly in the amount of olivine and belonging to the genera 2 and 26 of the olivine-basalts; they would be classed, as far as appearance goes, as porphyrites; their specific gravity ranges 2·85 to 2·90. The rock exposures were, however, scanty; and but little information could be obtained of the mode of occurrence. No scoriaceous rocks were found except in the instance of a compact dark basalt without plagioclase phenocrysts, apparently a dyke rock, and belonging to genus 40 of the olivine-basalts.

(*e*) *Ascent to the Summit of Seatura from Ndriti*.—The town of Ndriti lies in the great gap in the south-west side of the mountain which has been previously mentioned as probably an old crateral cavity. After traversing a district of highly altered basic rocks or propylites, to be subsequently described, and reaching an elevation of about 400 feet above the sea, I came to the long slope that leads up to the summit. A dense forest hid everything from view, so that the compass and aneroid had alone to be relied on.

At first one traversed a series of step-like alternations of level ground and steep "rises," until the old site of the village of Seatura, about 1,200 feet above the sea, was reached. There are some strange legends connected with this old mountain-village, which is now only indicated by little piles of stones and the debris of a wall, and was evidently abandoned long ago. We finally reached the summit by following up a spur or ridge in a northerly direction from Seatura. There was a precipitous descent on either side of the ridge with evidently a broad, deep valley to the eastward. The summit was rounded; but on account of the forest no view could be obtained. There was never any extensive exposure of rock noticed during the ascent; but all the way up occasional small blocks of a blackish olivine-basalt were observed on the surface, of the same general type as that found all around the mountain and referred to genus 37 in the synopsis.

(*f*) *The Ndriti Basin or Gap*.—This great hollow in the side of Seatura, which I have named after the town in its midst, is apparently a crateral cavity now drained by the Ndama river, and its tributaries, and covered with dense forest to such a degree that a general view of the whole is impracticable. The glimpses, however, that one obtains of the mountain scenery are very grand, the town

of Ndriti lying in the midst of mountains that rise almost on all sides of it except on the west. This great cavity is contracted at its mouth a little below the town and expands in its interior, where it must be two or three miles in width. Its floor is fairly level and is elevated only about 200 feet above the sea ;¹ whilst its mountainous sides rise to 2,000 feet and over.

As shown in the map there are two breaks in the outline of this ancient crater, the one on the west through which the Ndama river flows, the other on the south where the dividing ridge, separating it from the Nandi Valley is under 700 feet in elevation. The Nandi Gorge, as I will term the last-named, is a narrow picturesque ravine leading through the mountains from Nandi to Ndriti. One follows up a rocky stream-course hemmed in by precipitous sides until the top of the gorge is reached, when the watershed is crossed, and the descent is then made to Ndriti by one of the tributary stream-courses of the Ndama river.

Two or three large rapid streams, after draining its mountainous slopes, unite within the basin to form the Ndama river, which, as it issues from its mouth, becomes a comparatively placid stream rolling sluggishly along to the sea, some five or six miles away, with an average drop of about thirty feet in a mile. In the course of ages the original configuration of this great hollow has doubtless been extensively modified by the denuding agencies. The rainfall on the mountain-slopes must be very great, probably not under 250 inches in the year²; and Ndriti, though only 200 feet above the sea, is in all probability on account of its situation one of the wettest places in the island. The rivers have evidently been important factors in reshaping the original cavity.

Nearly all the rocks exposed *in situ* in the beds of the rivers and streams in the floor of the great Ndriti basin, and for 300 or 400 feet up its sides are more or less highly altered basic rocks, to which the old and the new names of greenstone and propylite may be fitly applied. They often sparkle with pyrites, and not uncommonly effervesce with an acid, so that one is apt to imagine

¹ In one of my traverses I crossed a level district extending a mile N.E. of Ndriti without changing my elevation.

² At Delanasau, on the north or dry coast of the island, the average rainfall, according to many years' observations by Mr. Holmes, is about 115 inches. At Wainunu, near the wet or south coast, the observations of Mr. Barratt and others extending over 16 years give an average of 160 inches. In the mountains this would be nearly doubled.

one's self in a region of limestone. The degree of alteration varies considerably, those most altered being light-coloured and greenish, whilst the others are darker, the specific gravity ranging from 2·69 to 2·79. In spite of these differences almost all of them appear to belong to the same eruptive series, being as a rule sharply distinguished from the prevailing unaltered surface basaltic rocks of the slopes of Seatura by the size of the feldspars of the groundmass, which average about ·3 mm. in length, whilst those of the basaltic rocks just alluded to average only ·17 or ·18 mm. long. These rocks are also well displayed in the sides of the Nandi Gorge; and from their mode of exposure by river-erosion, as well as from their relatively coarse crystalline texture, and from their alteration, it may be inferred that they are older and more deeply situated than any of the Seatura rocks before referred to. Whether these rocks, which extend over an area of some square miles, have been altered by solfataric action or contact-metamorphism,¹ I will not now say. The fact remains, however, that they are best exposed wherever the streams have worn deeply into the floor, and lower slopes of the great basin, or have cut down into the mountain-mass as in the case of the Nandi Gorge. The rocks that lie in loose blocks on the surface either at the bottom of the basin or on its slopes extending even to the very summit of the mountain (see page 67), are characteristic blackish olivine-basalts of the type prevailing around the mountain's slopes. These propylites are most frequently exposed as dykes in the beds of the rivers at the bottom of the basin. Such dykes vary from 4 to 6 feet in thickness, and they are very conspicuous when they stretch across the river's breadth projecting more or less above the water. From their frequency it may be inferred that in many other small exposures, ill suited for displaying the mode of occurrence of the rock, we have also to deal with dykes. Judging from four dykes that were particularly examined, they are all vertical or nearly so, and all run in much the same direction, namely, N.N.W.—S.S.E. or N.W.—S.E., whether on the north or south side of the great basin. In one instance, a rudely columnar structure across the thickness of the dyke was observed. From their exposure in river-beds it was rarely possible to ascertain much more than is given above. However, in the bed of a river, a mile above Ndriti, there was an extensive exposure of a highly

¹ This question, which has so often been raised with respect to the propylites, will probably receive a different answer from different localities. The matter is further discussed on later pages.

altered greenish rock which was crossed by a vertical dyke, 4 feet thick, formed of a dark grey less altered rock. I have referred these two propylites to two different genera of the augite-andesites, the dyke-rock to genus 2, and the other to genus 4. In the case of the dyke the rock is a little vesicular; whilst in the other it is densely charged with pyrites. Both have been subjected to the same alteration; but in a different degree; and it would thus seem that solfataric influences were here in operation before and after the intrusion of the dyke.

With reference to the characters of the alteration of these rocks of the Ndriti basin, it may be remarked that where the change is greatest the feldspars of the groundmass are alone recognisable. The plagioclase phenocrysts are quite disguised by alteration products, and chlorite, viridite, epidote, calcite, pyrites, &c, occupy much of the groundmass. Other rocks are less affected and in a few the change is only slight.

With regard to the prevailing types of the propylites of the Ndriti Basin, it has already been observed that in most of them the feldspar-lathes of the groundmass are unusually large, the average length being 3 mm. From the rare occurrence of olivine in some of the rocks that are but slightly changed, it is to be inferred that most of them belong to the augite-andesites, and might be termed doleritic basaltic andesites. But in other respects they differ considerably, both as regards the presence or absence of flow-arrangement of the feldspar-lathes, and in the occurrence and size of the plagioclase-phenocrysts, some having large porphyritic crystals, others small phenocrysts, and others none at all. Many of them contained a little interstitial glass. In my classification of the augite-andesites they are assigned to genera 2, 4, 16, &c., and additional particulars concerning their characters are given in the description of those genera. Judging from the average large size of the feldspar-lathes it may be held that, although in other features they often differ, some of the general conditions under which they were produced were the same.

On the right bank of the Ndama river, opposite Ndriti, there is a singular association of a vertical dyke of a bluish-grey basic andesite with a reddish scoriaceous lava, apparently a flow. The dyke is about 4 feet thick and runs N.W. and S.E., like the other dykes of the basin, exhibiting also a rudely columnar structure across its breadth. Where the two rocks are in contact, the dyke has a vitreous border half an inch thick, and an offshoot of the

dyke, four inches wide, has penetrated the lava, acquiring at the same time a more glassy texture. The small size of the felspar-lathes of both rocks distinguishes them from the dyke rocks of the basin, where the felspars are twice as long. Both rocks show some degree of alteration.¹

In following the valley of the Ndama River from Ndriti to Telana, about three miles farther down, one traverses a picturesque region. Emerging from the great basin the river flows through the rolling plains of the "talasinga" district. Near Ndriti, and occasionally on the way to Telana, is exposed a scoriaceous grey basaltic rock; and between two and three miles below Ndriti there is to be observed in the river-bed evidence of a comparatively recent flow of a highly basic scoriaceous lava from the ancient crater of the Ndriti basin. The rock, which is dark and fresh-looking, shows large porphyritic crystals of augite and olivine but no plagioclase, whilst the groundmass contains a little brown interstitial glass. Its characters will be found described under genus 3 of the olivine-basalts (p. 255). Its specific gravity, notwithstanding its large empty steam-pores, is 2.91. It differs markedly from the basaltic rocks of the Seatura slopes and the Mbua and Ndama plains, in the great porphyritic development of augite and olivine, in the large size of the felspars and augite of the groundmass, and in its numerous steam-holes. But in the coarseness of its small felspars it belongs to the same type as the altered or propylitic basic rocks of the Ndriti basin. It is probably by some such lava

¹ The dyke-rock has a specific gravity of 2.7; but is slightly vesicular. It shows a few small plagioclase phenocrysts in a groundmass of felspar-lathes, augite grains and prisms, magnetite, and a little brown interstitial glass. The felspar-lathes average .14 mm. in length and are for the most part not parallel. Secondary calcite occurs in the groundmass, and the powdered rock effervesces a little in an acid.

The rock forming the offshoot of the dyke differs only from the parent rock in its more vitreous character. Although the felspars and augites of the groundmass are fairly developed, the residual glass is much more copious, and in places where it has segregated, forming "lakelets," it has been subjected to an alteration often observed in palagonite when there are concentric alternating zones of a tan-coloured fairly refractive material and calcite.

The reddish scoriaceous lava in contact with the dyke shows no phenocrysts. The groundmass displays more or less parallel felspar-lathes, .1 mm. long, augite grains, and much magnetite. The residual glass is fair in quantity; but is mostly gathered into "lakelets" of brown altered glass with sometimes calcite in the centre.

The vitreous border of the dyke is composed of a dark glass quite opaque on the outer portion, but clearer and showing incipient crystallisation in the inner portion.

flow from the old Ndriti crater that the submarine bank was formed off the adjacent coast on which the low Lekumbi promontory has been built up.

In the numerous dykes of the Ndriti basin and in the great alteration which their rocks have frequently undergone, we have evidence in support of the view that this is an old crateral cavity, an opinion that is supported by the indications of lava-flows that have issued, apparently in later times, from the mouth of the basin. Reference has already been made to the locality where a dyke-rock and the rock-mass, into which it has been intruded, are both propylitic; and from this and other facts, such as the varying degrees of alteration in different parts of the basin, it is to be inferred that in the last stage of the activity of this vent its bottom and sides were extensively affected by solfataric influences. Since that period, the configuration of the crater-basin has been greatly modified through the denuding agencies.

The absence, or at least the great rarity, of tuffs and agglomerates in the case of Seatura is remarkable. The mountain has evidently been built up in the mass by flows of basic lava; and from this source have no doubt in an important degree been derived the basaltic flows of the Ndama, Mbua, and Sarawanga plains, great streams of basalt that further seaward have helped to form the submarine platform extending several miles from the coast. The submarine tuffs and agglomerates that occur at various elevations, reaching as high as 1,200 feet above the sea, in the Sesaleka, Lekutu, Sarawanga, and Ndrandramea districts lying to the north-west, north, and east, did not come under my notice on the Seatura slopes. On the other hand, except in the few localities, where scoriaceous rocks occur, the general type of the basalts is such as we would expect to find in submarine flows. In no part of the island, however, is the antiquity of the land-surface so well attested by the disintegration of the basaltic flows, which extends here to depths of ten and even twenty feet. This is in favour not only of the sufficiency of time, but also of the ability of the denuding agencies to strip off the surface-deposits.

However this may be, it is evident that the mountain of Seatura possesses a history quite independent of that of the rest of the island. I have pointed out in Chapter I. that it represents a mountain of the Tahitian type. In its radiating valleys and in its basaltic character it much resembles the mountainous island of Tahiti, which Dana describes as a gently sloping cone of the

Hawaiian order that through the erosion of ages has become a dissected mountain.¹

THE SEATOVO RANGE.—This remarkably situated mountain-range, which I have named after a town at the foot of its western slope, extends from the valley of the Ndama River to Solevu Bay. It attains a maximum height of about 1,800 feet, and varies between this elevation and 1,500 feet until in the vicinity of Solevu, where it descends as a mountainous headland to the coast. Its summit is narrow and ridge-shaped, and although the whole range is not interrupted by gaps it has a composite origin. At its north end, where it is cut off from the Seatura Range by the Nandi Gorge it helps to close in the large Ndriti basin. Towards the south an offshoot proceeds eastward and shuts in Solevu Bay. But, although apparently all the rocks are basic, considerable variety prevails, and there are many puzzling points in the geological structure of this region.

At the place where this range abuts on the Ndama valley, below Ndriti, the grey scoriaceous basalt, before referred to, is exposed at its foot. However, the usual blackish basaltic rocks, often carrying a little olivine, form in mass the mountainous southern headland that culminates in Solevu Peak (Ulu-i-matua); and the same rocks prevail in the lower regions on the west side of the range from Vuia Point to the valley of the Ndama River. The southern portion will be described in the account of Solevu Bay; and I will now give the results of my journey across the summit of the range about half a mile south of the Leading Peak of the chart.

The eastern slopes are steep and often precipitous, whilst on the western side there is a more or less gentle descent to the lower levels, suggestive of a volcanic slope; and it is remarkable that whilst the rocks exposed on the precipitous eastern side for the lower two-thirds are sometimes markedly altered, on the western side they are comparatively unchanged. These facts at once suggest that we have here the western rim of a large crateral cavity, though the topography of this district is not sufficiently well shown in the chart to enable one to define its original limits. This inference is also supported by the occasional scoriaceous character of the rocks below referred to.

The most frequent rocks in the upper two-thirds of the range are grey porphyritic olivine-basalts, displaying opaque plagioclase phenocrysts and more or less hematized olivine, the specific gravity

¹ *Characteristics of Volcanoes*, 1890.

being about 2'9. They approach in characters the grey porphyritic olivine-basalts of the northern part of Seatura (pages 65, 66); but differ amongst other features in the greater abundance of the olivine and in exhibiting flow-structure. They are usually almost holocrystalline, and are assigned for the most part to genus 14 of the olivine-basalts. They are extensively exposed in the stream-courses on the west side between 500 and 900 feet; and huge masses of the same rocks, but containing less olivine and more glass, and displaying much calcite, viridite, and other alteration products, are found near the base of the eastern slopes. The semi-vitreous condition of these rocks is represented in the large masses of a dark very scoriaceous porphyritic lava, possessing quite a cindery appearance, that occur on the narrow ridge-shaped summit. The groundmass shows a few scattered felspar microliths; but it is in the main composed of a dark opaque glass. Small cube-like crystals of chabazite line some of the cavities.

Other basic rocks are not infrequent and apparently represent dykes. Thus on the eastern side at 800 feet is exposed a dark-grey semi-ophitic doleritic rock (sp. gr. 2'77) assigned to genus 12 of the augite-andesites (page 275). The felspar-lathes average '3 mm. in length, and there is a little interstitial glass containing viriditic and calcitic alteration products, the same materials filling small rounded vesicular cavities. On the same slope between 1,000 and 1,200 feet, there are displayed fresh-looking compact non-porphyritic basaltic andesites (sp. gr. 2'84), where the felspar-lathes average '2 mm. and the interstitial glass is scanty. They are referred to genus 16, species C, of the augite-andesites. On this side also between 600 and 800 feet occur blocks of a highly altered slightly vesicular augite-andesite showing a little microporphyritic plagioclase. It is assigned to genus 13, species B, of the augite-andesites. In one place where it is in position it is scoriaceous, the steam-holes being round, empty and one to five mm. in size. In the less glassy rock it displays numerous small irregular cavities either filled with fibrous viridite or calcite or showing concentric zones of the two minerals. The felspar-lathes are '15-2 mm. in length. In blocks near the foot of the eastern slope occur a blackish olivine-basalt (sp. gr. 2'88) of the prevailing Seatura type, possessing a little interstitial glass and felspar-lathes with an average length of '2 mm. It belongs to genus 25 of the olivine-rocks. . . . On the western slopes at a height of 500 feet occurs a dark compact rock (sp. gr. 2'89) with abundant olivine which is referred to genus 1 of the olivine basalts. There is a little residual glass, the felspar-lathes

averaging only .08 mm. in length. A similar-looking rock is exposed at 1,400 feet, which displays felspar-lathes averaging .2 mm. long (sp. gr. 2.9). It belongs to genus 37 of the same olivine class. Here also is assigned an aphanitic basalt, with a few scattered large plagioclase phenocrysts and felspar-lathes averaging .15 m. long, which is displayed near the base of the slope.

I could not satisfy myself as to the presence of tuffs on the slopes of this range. Some fine argillaceous rocks exposed half-way up on either side show no lime and contain no organic remains. One specimen beside me is certainly a disintegrated basic rock. No agglomerates came under my notice. In the absence or rarity of detrital rocks this part of the range resembles the adjacent mountain of Seatura.

Although olivine-basalts prevail in this part of the Seatovo Range there is great variety in their characters; and it does not appear possible to explain such a diversity except to assume that we have here an old crateral ridge which has again and again been penetrated by dykes and has since been greatly denuded. We have here one of those singular mountain-ridges that characterise the central portion of the island, but differing in this respect that the submarine tuffs and agglomerates, which there occur on the surface, even in the higher levels, are here absent.

SOLEVU BAY.—There are few localities in the island where so many kinds of basic rocks are displayed as around Solevu Bay. In addition to the prevailing blackish porphyritic basalts and basaltic andesites, there are grey porphyritic basalts, grey non-porphyrific basalts, black basalts with abundant large crystals of olivine, &c., all of which have their distinctive characters.

This picturesque bay is surrounded by hills. On the west side it is inclosed by the promontory forming the southern extension of the Seatovo range which, culminating in Ulu-i-matua, or the "Head-of-the-Strong" peak, descends at first steeply and then gradually to the coast, where it projects as Vulavulandre Point. On the east side is a broken line of hills, of which Koro-i-rea, the hill known to the natives as the "Town of the Albinos," is the most conspicuous. Beyond it stretches the eastern point of the bay, which the Fijians call "Ua-nguru," that is, "the noise of the waves." On the shores lie the village of Nawaindo, "the running-stream," and the once populous town of Solevu, which has given its name to the bay. Solevu, as its name indicates, is the place of the "great assembly." In the background rises the three-peaked mountain of Koro-tolutolu, "the three towns," which forms

a continuation inland of the eastern arm of the bay, and joins the Seatovo Range at the head of it. Between these two ranges enclosing the bay lies the valley of Solevu, down which descends the Solevu River to the sea. In ascending this valley from the shore, one rises only about 100 feet above the sea for the first mile or two.

The promontory, which in the even-topped Ulu-i-matua or Solevu Peak, attains a height of 1,100 feet above the sea, displays on its summit and on its eastern slopes descending to the Solevu river, and on its western slopes reaching down to the coast at Vuia, more or less porphyritic blackish olivine-basalts of the usual type with specific gravity 2·88—2·90. These basaltic rocks contain scanty olivine and only a little interstitial glass. The felspars of the groundmass vary in different localities from ·11 to ·15 mm. in average length. The rocks belong to genus 37 of the olivine class which is described on page 262.

They are in the lower regions often decomposed to a considerable depth, the spheroidal structure being well displayed during the weathering process. Where this promontory terminates in the low Vulavulandre point, these rocks give place in part to grey porphyritic olivine-basalts, with specific gravity 2·79—2·83, which from the abundance of the macroscopic opaque felspar look like porphyrites. They come near to the rocks exposed on the north slopes of Seatura and in the Seatovo Range. At the end of the point they become scoriaceous and more vitreous; but with this exception they contain but little glass. They vary somewhat in character and are referred to genera 2 and 38 of the olivine-class.

The prevailing rock in the interior of the Ua-nguru promontory to the south of Koro-i-rea is the blackish porphyritic basalt, containing a little olivine, and often much decomposed; but at the point and on the east shores of Solevu Bay, there is a considerable variation in the character of the basic rocks, of which the two following are the most conspicuous. Near the village of Nawaindo, there is an apparent intrusion of a black lava-like basalt of high basicity (specific gravity 3·01) showing abundant large olivine crystals, five or six mm. across, with some porphyritic augite, but no macroscopic felspar. At the point the rock is somewhat scoriaceous, with calcite occasionally filling the cavities, whilst the olivine is so thoroughly hæmatised that it glistens like brown mica. The compact rock contains a little devitrified interstitial glass, the felspar-lathes being unusually small, their average length being only ·07 mm. It belongs to genus 15, the most basic of the genera of the olivine class represented in the island. The

second rock to be noticed is a slightly altered compact basalt without olivine forming apparently a dyke near the coast about half way between the village of Solevu and Ua-nguru Point. It has a specific gravity of 2·84, the felspar lathes (·15 mm.) presenting a marked flow-arrangement, whilst there is a fair amount of altered residual glass in irregular spaces, a millimetre in size. The rock, on account of its joint-structure, could be easily worked as a building-stone. It is referred to genus 16, species B, of the augite andesites.

The hill of Koro-i-rea, which rises on the east side of the bay to a height of 850 feet, has a ridge-shaped summit. Its upper half is composed of a bluish-grey rock looking like a phonolite and usually compact, except at the top of the hill, where it is a little scoriaceous. It has, however, a specific gravity of 2·91 or 2·92, and is in fact a pretty grey olivine-basalt studded with small olivine crystals about a millimetre in size and showing no other phenocrysts. This type of olivine-basalt occurs also at Ulu-i-ndali on the east side of Wainunu Bay, but is rare in the island. It differs amongst other features from the porphyritic olivine-basalts of the northern part of Seatura and of the Seatovo range in the absence of plagioclase phenocrysts. There is apparently no interstitial glass, whilst the average length of the more or less parallel felspar-lathes is ·13 mm.¹ On the lower slopes of the hill the common blackish porphyritic basalt or basaltic andesite is exposed. In the grey-basaltic upper portion of this hill we have probably an old volcanic "neck."

Following the line of hills inland from Koro-i-rea, we cross the intervening saddle 450 feet above the sea, and ascend the slopes of Koro-tolutolu, a ridge-shaped mountain backing Solevu Bay, and having, as its name indicates, three peaks, of which the highest is 1,280 feet above the sea. My observations indicate that this mountain is formed in mass of the common blackish-basalts described under genus 37, their specific gravity being 2·88 to 2·94. But Koro-tolutolu has also the peculiarity that it appears to be in mass magnetic. The rocks obtained from its summit, half-way up its western slopes, and near its foot on the same side, all display polarity, a character also of the rocks of the neighbouring hills of Ulu-i-matua and Koro-i-rea, but in their cases seemingly confined to the higher levels.²

Neither tuffs nor agglomerates came under my notice at Solevu Bay. This appears to be an ancient corner of the island, from

¹ Referred to genus 16 of the olivine-basalts.

² This subject is discussed in Chapter XXVI.

which denudation has stripped off nearly everything that could guide us in speculating as to its past. Although the hills of Koro-i-rea and Koro-tolutolu doubtless represent old volcanic necks, the relation of Ulu-i-matua to the very differently composed northern part of the same range, as described on page 73, is extremely puzzling. Then again in the opposite sides of Solevu Bay we see exposed the remains of lava-flows that bear no relation to the present configuration of the surface. We may suspect, however, that most of the volcanic energy was displayed under the sea.

NANDI BAY.—Lying north of Solevu Bay, this bay is situated between spurs, descending to the coast from the mountainous interior. The valley extends a long distance inland without much change of level, the elevation $1\frac{1}{2}$ miles from the coast being not over 100 feet above the sea. At its head is the Nandi Gorge, which leads into the Ndriti Basin, the great crateral cavity of Seatura. There are some remarkable lofty, isolated hills in this valley that would be well worth examining.

That the bay represents the site of an old volcanic centre is indicated by the occurrence on the shore of two basaltic dykes, one on either side of the village of Na Savu and 300 to 400 yards apart. The eastern dyke is perhaps 30 feet thick, whilst that to the west is scarcely half this thickness. They exhibit an imperfect columnar structure, the columns, which are 6 to 12 inches across, being inclined at an angle of 15° or 20° from the vertical in such a way that it may be inferred that the molten material was ejected from some subterranean focus lying to the northward (or inland) at an angle of 15° or 20° above the horizon. The basalt is a compact bluish-black rock with specific gravity 2.95–2.99. It contains abundant olivine but no other phenocrysts and very scanty interstitial glass, whilst the felspar-lathes average .1 mm. in length. It is referred to genus 16 of the olivine basalts, and is remarkable for the flow arrangement not only of the felspar-lathes but also of the smaller olivine crystals.

Blackish basaltic rocks of the prevailing type are exposed on the surface of the broad spur, not over 500 feet in height, that divides the Nandi and Nasawana valleys and descends to the coast between the two bays thus named. They belong to genus 37 of the olivine-basalts and display a few small plagioclase phenocrysts. The felspar-lathes average .2 mm in length, and there is a little interstitial glass. Entering Nasawana Bay we find ourselves on the southern slopes of Seatura, of which the high Na Suva range that backs the bay is the southern extension.

THE TABLE-LAND OF NA SAVU.—This remarkable plateau has an elevation varying usually between 700 and 800 feet above the sea and a maximum breadth of four or five miles. It is an area of basic agglomerates and basic tuffs and lies in the hollow between the basaltic mountain of Seatura and the acid andesitic hilly region of Ndrandramea. For the convenience of description I have named it after the picturesque falls of Na Savu¹ at its southern edge. These falls are celebrated in Fijian tradition; and from the brink in old time the native desirous of ending his life leapt into the gorge below.

After flowing sluggishly along on the surface of the table-land, the Mbutu-mbutu River arrives suddenly at the edge of a line of cliffs of volcanic agglomerate, that here form the southern border of the plateau, and with a volume 30 to 40 feet across, it plunges down into the ravine 150 feet below. As shown in the view from the gorge below, there is a break in the middle of the descent. These falls, however, are not easily accessible. They are best approached by proceeding from Wainunu to Ndawathumi and thence up the gorge of the Mbutu-mbutu River.

The surface of the plateau of Na Savu is densely wooded. In places it is marshy, and here thrives the Giant Sedge (*Scirpodendron costatum*). The Makita tree (*Parinarium laurinum*) also flourishes in the wet districts; and in the drier localities occur the Ndakua (*Dammara vitiensis*) and the Ndamanu (*Calophyllum burmanni*) together with a palm of the genus *Veitchia*. Here on this level watershed between the basins of the Wainunu and Surawanga rivers, the sluggish streams flow aimlessly along in but slightly eroded channels; and it is not always possible to determine the side of the island to which they ultimately direct their course. In their beds are pebbles and irregularly formed concretions of an impure reddish flint which I have described on page 354. On the north and south sides the table-land is much excavated by the tributaries of the Sarawanga and Wainunu rivers. On the west where it meets the foot of the Seatura slope portions of columns of basaltic rocks appear on the surface, and deep gorges are worn by the large streams descending from the mountain. On the east towards Nuku-ni-tambua and Tambu-lotu, the surface is also much cut up. The preservation of this table-land in a region, where the denuding agencies are very active in their operations all around it, is to be attributed to its being a level watershed, where the head-

¹ "Na Savu" is the Fijian for waterfall. The complete name of this fall is "Na Savu ni nuku."

waters of the Wainunu and Sarawanga rivers in part take their rise but have little or no eroding power.

It is not easy to obtain a good general view of the district of the falls on account of the dense forest-growth. When making the traverse from Tambu-lotu to Ndawa-thumi, it is observed that there is here a singular hollow, about half a mile in length, which receives the falls at the western end. The river crosses this hollow and is at once received into the gorge below, but there is no stream to explain the origin of the cavity. On its north side the cliffs of agglomerate rise to a height of 150 to 200 feet from their base, but on the south the sides are much lower. Here there seem to be the remains of the crater of the ancient vent from which all the tuffs and agglomerates of the district were derived. We must look for their origin in the vicinity, and the only evidence of a crateral cavity is this streamless hollow extending east from the falls of Na Savu.

With reference to the basic tuffs and agglomerates of this plateau it may be observed that they cover the massive basic rocks and are probably not over 100 or 150 feet in maximum thickness. They are well exposed where the streams cut into the borders of the plateau. The tuffs are sometimes bedded and slightly inclined, and they may be fine or coarse grained. They are more or less palagonitised hyalomelane-tuffs, being composed mainly of fragments of a basic glass, often finely vesicular and even fibrillar, the vacuoles being filled with different materials, whilst the palagonitisation is well advanced. Sometimes they have a brecciated appearance, and in that case when the alteration of the basic glass is very extensive we find angular fragments, 1 to 2 inches across, of a greenish palagonite imbedded in a pale matrix of palagonitic debris, the whole rock having a soapy feel and a steatitic appearance. This is well shown on the sides of the stream-course at Ndawathumi which lies at the border of the table-land. These tuffs effervesce but slightly with an acid.

The basic agglomerate is displayed in the face of the falls and in the gorges. The blocks are as a rule composed of semi-vitreous basaltic andesites of varying type, showing no olivine and containing a fair amount of smoky glass in the groundmass. At times they are scoriaceous and display amygdules of calcite or a zeolite. In places the rock shows large phenocrysts of plagioclase and a semi-ophitic groundmass, when it is referred to the porphyritic group of genus 9 of the augite-class. In a few of the scoriaceous blocks the augite of the groundmass is for the most part prismatic and rarely granular (genus 5).

The massive rocks underlying the agglomerates in the vicinity of Na Savu are aphanitic augite-andesites, differing in important characters from the rocks of the agglomerates. They probably represent ancient lava flows of the Na Savu vent. They are compact (sp. gr. 2.72—2.76), and display a groundmass formed of a felt of felspar-lathes, averaging .05 or .06 mm. only in length, and in flow-arrangement. That occurring just below the falls is almost aphanitic, but is referred to genus 13, species A, sub-species *a*, of the augite-andesites. The rock from the gorge below is of the same character, but on account of its opaque plagioclase phenocrysts it is referred to genus 14, and is described on p. 279.

In one place on the plateau a tuff-agglomerate is penetrated by veins, a few inches thick, formed apparently of a finely brecciated tuff of basic glass fragments in a palagonitic matrix. It is, however, pointed out on p. 340 that they were originally veins of basaltic glass which have been subjected to crushing, and that the palagonite has since been produced.

In concluding this description of the table-land of Na Savu, it may be inferred that the source of its basic tuffs and agglomerates is to be found in the same locality; and probably the original vent is now represented by the hollow extending eastward from the falls. With the exception of a large block of silicified coral found in the vicinity of Ndawathumi and of the impure flints of the surface of the plateau, which are described on pages 354, &c., no direct testimony of its submarine origin offered itself to me. The palagonitic characters of the tuffs afford, however, indirect evidence in this connection; and indeed the occurrence of submarine tuffs and limestones in the vicinity of Tembenindio on its lower northern slopes (see page 131), and the existence at elevations of several hundred feet above the sea of fossiliferous tuffs and clays in the Wainunu and Ndrandramea districts to the eastward, afford strong presumptive evidence that the tuffs and agglomerates of the table-land were deposited under the sea, and I may add in a period subsequent to that of the formation of the great basaltic flows of Seatura and Wainunu.

CHAPTER VI

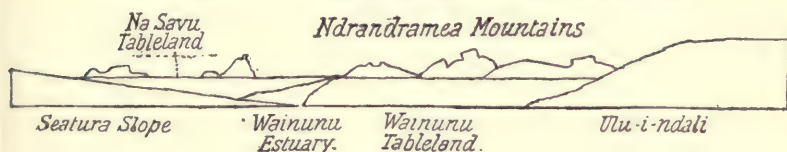
DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE BASALTIC PLATEAU OF WAINUNU.—This table-land extends for a distance of seven miles from the base of the Ndrandramea mountains in the heart of the island, where it is elevated 1,100 to 1,200 feet above the sea, to the valley immediately north of the hill of Ulu-i-ndali, where within a short distance of its termination it still retains a height of 700 to 800 feet. Limited on the west by the valley of the Wainunu River and on the east by that of the Yanawai River, its breadth varies usually between four or five miles. It is best seen in profile when viewed from the south-west on the western shores of Wainunu Bay, between Korolevu and Nasawana, when it presents itself to the eye as a table-land, descending with a very gradual slope from the interior towards the coast. From such a point of view the two great basaltic slopes of Seatura and Wainunu may be seen together, the former descending eastward to the Wainunu valley at an angle of 3 or 4 degrees, the latter descending at right angles to it to the southward with a similar small gradient of 2 or 3 degrees.

In the profile of the island attached to this work the Seatura slope is well shown; but that of the Wainunu table-land being seen from the south is represented only by a level contour-line at the base of the Ndrandramea mountains. The two great series of basaltic flows, though closely approaching in a direction at right angles to each other, do not come into actual contact, and the intervening space is now occupied by the valley of the Wainunu River. In the accompanying rude outline-sketch of this region, as seen from off the mouth of the Wainunu estuary, the relation of this valley to the two great series of basaltic flows is clearly

shown. On the left is the foot of the Seatura basaltic slope ; on the right is the Wainunu basaltic table-land ; and between them lie the estuary and valley of the Wainunu, at the back of which appears the " Na Savu " table-land, formed of basic tuffs and agglomerates. Behind all there rise up suddenly the Ndrandramea mountains formed of acid andesites ; whilst in the foreground to the right is the hill of Ulu-i-ndali, which is composed in the mass of a grey basalt of a type quite different from the blackish basaltic rocks of the Seatura slope and of the Wainunu table-land. It was from this view off the mouth of the estuary that I received my first lesson in studying the structural formation of the island. I kept

Profile, looking north from off the mouth of the Wainunu River.



it always in my mind's eye, and for months in an almost unmapped region it was my only guide.

The gradual slope of the Wainunu table-land from an elevation of 1,100 or 1,200 feet in the interior to 700 or 800 feet near the coast has already been referred to. Beyond this lower limit it descends much more rapidly and within less than a mile it terminates at Masusu in a steep-sided declivity 300 feet high opposite Ulu-i-ndali, and in a gentler slope on the eastern side in the Ndranimako district. Its somewhat undulating surface is well wooded ; but on account of the small gradient the small streams on the table-land do not excavate deep channels, but flow slowly along in shallow courses and often stagnate in swampy land where the interesting "*Scirpodendron costatum*," the giant-sedge, flourishes. In their beds occur reddish flinty concretions, up to 3 inches across in size, and magnetic iron sand in great abundance. A sample of this sand roughly washed on the spot contains 77 per cent. of magnetic iron.¹

Basaltic rocks, often exhibiting a columnar structure, are exposed at intervals on the surface and slopes of this table-land all over its area. Now and then when traversing this region one

¹ The flinty concretions are described on page 354, and the iron sand on p. 356.

comes upon a tract strewn with large blocks, amongst which occur fragments of huge columns 3 to 4 feet in diameter ; but it is on the steep southern slopes of the plateau in the vicinity of Ndavutu and Masusu that the most extensive exposures of columnar basalt are to be found. Here there have been large clearings made for the tea-plantations, and portions of columns 2 to 3 feet in thickness are scattered all over the slopes and surface of Masusu.

A very interesting exposure occurs on the southern edge of the Masusu flat facing Ulu-i-ndali. Here there is displayed in the face of a waterfall a mass of basalt about 40 feet deep, formed of regular cross-jointed columns, 3 to 4 feet in diameter and often pentagonal in shape, which are almost perpendicular, being inclined about five degrees from the vertical. But in the upper portion of the fall the columns are smaller (2 to 3 feet across) and become arched and nearly horizontal. This was the only section of the inner mass of the basaltic flows that I found, and here the columns are almost vertical. In this locality several other exposures of the columnar basalt occur ; but they are all at the surface and the columns are nearly horizontal or very much inclined from the vertical, being often pentagonal in form, 2 to 3 feet across, and sometimes curved with joints 10 to 20 feet in length.

Neither vesicular nor scoriaceous rocks came under my notice in this region, and the presence of pteropod-ooze deposits and of foraminiferous clays and tuffs on the slopes of the basaltic tableland indicates that the flows were submarine. The common character of a sub-aërial basaltic flow, where there are large vertical columns below and smaller radiating columns above, did not present itself ; and it is probable that the singular arrangement of the columns in the upper portion of these flows may be connected with the conditions of depth under which the flows took place.

It is apparent from the description given by Dana of the columnar basalt of Tahiti¹ that it was formed under different conditions from those under which the basaltic flows of Wainunu and Seatura were formed. The columns composing a cliff 500 feet high in the Matavai valley were 10 to 20 inches across. A bluff, 200 to 300 feet high, in another part of the valley, was made up of columns 5 to 8 inches in width. The tallest cliff displayed in places converging and curved columns, which is attributed to the unequal cooling of the interior of the mass ; but it is evident from a diagram given by the author that the columns were not

¹ *Geology of the United States Exploring Expedition.*

inclined at a large angle from the perpendicular.¹ He also refers to some prisms of a grey basalt exposed just below the Wailuku Falls near Hilo in the large island of Hawaii which were 8 feet in diameter and were surmounted by others only 1 to 4 feet across.

The basalts of the Wainunu table-land are blackish and non-vesicular, with a density of 2·87 to 2·90. They all carry olivine and microporphyrific plagioclase, and display a little interstitial glass, and the felspar-lathes are usually in plexus-arrangement, being stout and often showing twin lamellæ. But the rocks exhibit important variations in different localities as regards the amount of olivine, the length of the felspar-lathes, the presence or absence of the ophitic character, &c., and they are grouped in different genera of the olivine class (1, 13, 25, 33). Probably the type of genus 25, with scanty olivine and granular augite, would prevail.

From the varying size of the felspars of the groundmass it is apparent that the flows are not all of the same character. At Masusu, where the rock is doleritic in texture, they average from ·25 to ·3 mm. in length. A mile further north, they are about ·17 mm. long, and two miles more to the north they average only ·1 mm. in length. It is probable that a semi-vitreous basaltic andesite (spec. grav. 2·73), that shows no olivine and is referred to the porphyritic sub-genus of genus 9 of the augite-andesites, which is exposed in the stream-courses near the base of the dacitic mountains of the interior, is the product of a later eruption. Occasionally one finds, as at Thongea in the Wainunu valley, a basalt rich in olivine (spec. grav. 2·95), the felspars of the base averaging ·1 mm. in length. It may be remarked here that one cannot draw a sharp distinction between the basalts of this region and those of the adjacent eastern slope of Seatara. Their specific gravity is about the same (2·87 to 2·90); but the coarse texture of the Masusu basalts did not come under my notice in the last locality, where the felspars of the groundmass average ·18 mm. in length or about two-thirds the length of those of the Masusu rocks.

By referring to the section across this part of the island, it will be observed that the basaltic lavas of this table-land must have issued from some fissure near the south side of the base of the Mdrandramea mountains. In crossing the head of this plateau

¹ A similar arrangement was observed in the columnar basalt of Kauai in the Hawaiian Islands. It is presumed that these Hawaiian flows are sub-aerial.

on the way from Nambuna to Ndrawa one passes from the region of the acid andesites into that of the basalts. The track first skirts the base of Mount Wawa-Levu, where the prevailing altered dacitic rocks are exposed in a much decomposed condition in the stream-courses. Then there is a gradual ascent through somewhat broken country to reach the western slope of the table-land, and here are at first displayed the semi-vitreous basaltic andesites just referred to.

The Wainunu table-land is bisected in a singular fashion by the Ndavutu River. Since, however, the deep and often gorge-like channel of the river displays submarine deposits incrusting the basaltic slopes on its sides, it is evident that the break in the basaltic table-land existed in part at least before the emergence.

With regard to the total thickness of the basaltic flows of this plateau I have only a few data. In the bed of the Ndavutu River opposite Vunivuvundi, and about 400 feet above the sea, there is exposed a greyish porphyritic rock showing pyrites, apparently an altered andesite. If this is the bed-rock, the basaltic plateau in that locality would be 300 to 400 feet in thickness. This is rather over the thickness of the end of the table-land at Masusu.

I pass on now to consider briefly the submarine deposits that overlies the marginal slopes of this basaltic table-land in places. They are for the most part pteropod and foraminiferous ooze-rocks and are extensively represented on the surface and slopes of the Nandua flat to the north of Ndavutu, where they occur at all elevations up to 500 feet above the sea. They are also displayed on the eastern slopes overlooking the Yanawai but at rather lower heights; and little patches of them occur here and there in different places but not exceeding 500 feet in elevation. These friable clayey rocks, which contain from 30 to 40 per cent of carbonate of lime, are described in detail on page 320. It may however be remarked here that these deposits are but partly derived from the degradation of the submerged basaltic table-land or from the washings of a basaltic coast. They were formed in a clear sea-way, but probably at no great depth, at a time when the basaltic plateau was submerged below the level of breaker-action.

It is remarkable that these deposits do not repose directly on the basaltic rock. In one place below the Nandua tea-plantation, where there is a steep descent to the river of about 250 feet, the pteropod ooze-rock, which is exposed in the upper half, passes down into a chocolate-coloured marl that contains 5 per cent of carbonate of lime and is horizontally bedded. It is composed in

the main of fine palagonitic debris, with some fragments of minerals, &c, and contains a few microscopic tests of foraminifera. This deposit passes down into apparently a rock of pure palagonite. The succession of these beds and their characters are described more in detail on page 344 ; and as indicated in the diagram there given it is to be inferred that a very extensive formation of palagonite has taken place on the surface of a submarine basaltic flow.

On a similar slope of the Nandua district, and about half a mile nearer Ndavutu, the pteropod ooze-rock overlies a coarse zeolitic palagonite-tuff composed in great part of fragments of a highly altered vacuolar basic glass, but without organic remains. These tuffs are horizontally stratified. Tuffs precisely similar occur on the northern slopes of Ulu-i-ndali three miles to the south. They are all described in detail on page.335.

Some miles up the valley of the Ndavutu River on the steep slope descending from Vunivuvundi to the river, and on the sides of the river lower down, are exposed dark palagonitic and sometimes calcareous clays and tuffs. I traced them as high as 450 feet above the sea where they were bedded and dipped gently to the west. In the river-channel they were mostly confined to the right bank, the slope on the other side being strewn with large fragments of columnar basalt. At the mouth of the Ndavutu River, there are exposed tufaceous sandstones and a tuff-conglomerate, probably in great part formed of palagonitic materials, but I have kept no specimens.

There is much that is puzzling about the tuffs of the region between Ndavutu and Vunivuvundi. The surface pteropod and foraminiferous ooze-rocks, that are found here and on the Yanawai or eastern border of the basaltic plateau and in other localities, offer no difficulties ; but the origin of the palagonitic tuffs that in places lie beneath them is not so easy to explain. At Mr. Simpson's old estate on the Nandua flat one finds numbers of huge blocks of columnar basalt scattered about on the slope descending to the river ; and in places there is exposed in a small stream, up to a height of 500 feet, a fossiliferous ooze-rock containing marine shells. The ooze-rock is evidently an incrusting deposit ; but when one goes down to the river-side, which is there about 200 feet above the sea, one finds displayed *in situ* in the river-bed an amygdaloidal basic lava with coarse tuffs and agglomerates a little lower down.

THE HILL OF ULU-I-NDALI.—The meaning of the name of this hill is "Head of the rope." It is noted on account of the dense

growth of tall forest trees that clothes its surface, such as the Vesi (*Afzelia bijuga*), the Ndamanu (*Calophyllum burmanni*), the Ndakua (*Dammara vitiensis*), the Wathi-wathi (*Sterculia* sp.) &c. ; and it may be that its name is connected with the launching of the large canoes that were at one time constructed on its slopes.

Ulu-i-ndali, which has a broad level summit 1,100 to 1,150 feet in height, rises on the left side of the mouth of the Wainunu estuary. Its relation to the surrounding region is partly shown in the rough sketch given on page 83. It is separated from the basaltic tableland to the north by a deep and wide valley, the bottom of which is raised only a few feet above the sea ; the small stream known as Ndawa-ndingo, that apparently flows through it, is merely a branch of the Wainunu estuary, the tide ascending it for some distance. This singular valley, like the main valley of the Wainunu, dates back in great part to the period preceding the emergence of this region. The steep basaltic slopes of Masusu, strewn with fragments of large columns, bound it on the north. On its south side are the lower slopes of Ulu-i-ndali which are composed of volcanic tuffs.

A long spur descends to the south from Ulu-i-ndali to form the rocky promontory of Vatu Vono or "Stone turtle," so-named from the fanciful resemblance of the large rounded blocks of basalt on the shore to the backs of turtles. To the south-east extend the low tuff-formed Ravi-ravi plains which are but slightly elevated above the sea. The Ulu-i-ndali range is apparently connected by a "col" with a range of similar height to the eastward, the highest peak of which is about 3 miles distant.

A more or less coarse doleritic grey olivine-basalt forms the mass of this hill and is chiefly exposed in its upper portion. Around its slopes, extending from the coast usually half way up the hill, are blackish-brown olivine-basalts ; they differ amongst other points from the grey basalts—which are practically holocrystalline, in their greater amount of interstitial glass, to which, doubtless, is due their dark colour. These dark basalts also occur scantily on the summit ; but from their greater prevalence on the lower slopes and from some other of their characters, it may be inferred that they are in the main formed at the surface. Outside all, on the north and south sides of the hill, are exposed coarse tuffs composed of fragments of palagonitised vacuolar basic glass and containing much secondary zeolitic and calcitic materials. They are purely of eruptive origin, and although containing no organic remains were doubtless, as in the case of the precisely similar tuffs of the neighbouring district of Nandua, deposited under the sea. A

description of their characters is given on page 335. Such tuffs extend as high as 300 feet above the sea on the north-west slopes, where there are exposures, 10 to 12 feet in thickness, in the dry stream courses; and here they may be seen overlying the basalt and rudely bedded, dipping away from the summit at an angle of 15 degrees.

The grey olivine-basalts of Ulu-i-ndali, which often look like clinkstone, range generally in specific gravity from 2.9 to 2.95. They contain microporphyrritic olivine in abundance, which is usually more or less hæmatised and in extreme cases of the change looks like brown mica. Most of them are referred to genus 16 of the olivine class and their characters will be found described on page 258. The felspar-lathes are stout and show sometimes lamellar twinning, and on account of their large size (.2 to .5 mm in average length) the rock acquires a doleritic texture. They display as a rule a flow arrangement around the olivine crystals. Augite granules occur in great abundance, and there is rarely any interstitial glass.

These grey olivine-basalts are as a rule non-vesicular, but rocks with minute irregular cavities, though without glass, occur scantily on the upper slopes. They come near to the grey olivine-basalts of the hill of Koro-i-rea in the Solevu district, as described on page 77; but they differ in their doleritic or coarser texture, the felspar-lathes in the last-named locality being much smaller, their average length being .12 mm.

The blackish basalts, mostly characteristic of the lower slopes of Ulu-i-ndali, vary somewhat in character; but they may on the whole be regarded as surface forms of the more deeply situated grey basalts which are practically holocrystalline. The rock of this kind that prevails on the south and west sides has a specific gravity of 2.96. It is referred to the same genus (16) as the grey basalts, but differs from them in the circumstance that the microporphyrritic olivine is serpentinised and not hæmatised, and in the occurrence of a fair amount of devitrified interstitial glass, to which probably the dark colour of the rock is due. . . . The dark aphanitic basalt, with flinty fracture and a specific gravity of 3.00, that is displayed in Vatu Vono Point, is merely a compact surface variety of the more coarse-textured grey basalts, being referred to the same genus. Here there is a great abundance of microporphyrritic olivine in a groundmass of parallel felspar-lathes and augite grains; but the felspars are unusually small, averaging .1 mm. in length; and there is a much larger amount of fine

magnetite than in the grey basalts. There seems to be no interstitial glass; and the olivine when not fresh is usually serpentinised but occasionally hæmatised.

The dark basalts of Ulu-i-ndali when they occur on its upper slopes become ophitic. A specimen lying beside me has a specific gravity of 2.91. Allowing for the structural differences, it appears as an ophitic surface variety of the deeper seated grey basalts. A description of it is given under genus 12 on page 256, of which it forms the type.

From the data above given, the hill of Ulu-i-ndali is to be regarded as the basal portion of a submarine volcano still retaining part of its ash-coverings. The grey doleritic basalts probably represent the core and the dark fine-grained basalts represent the flows of this ancient vent.

THE KUMBULAU PENINSULA.—South-east of Ulu-i-ndali stretches a remarkable "talasinga" district which for convenience I will call the peninsula of Kumbulau. Its south or seaward border is broken and hilly, and presents an irregular line of hills 300 to 470 feet in height, extending from Kumbulau Point to Soni-soni Island, which is almost connected with the coast. The rest of the peninsula is a low-lying and often marshy plain, which, though elevated in some places 20 to 25 feet above the sea, is usually much lower. On the north-east side of the isthmus is the narrow Nandi inlet, bordered by low mangrove-belts, which represents the broad channel that in a very recent period of the island's history cut through the present neck of the peninsula between the head of the Nandi inlet and Ravi-ravi.

Stratified and often steeply inclined tuff-sandstones and clays, more or less basic and palagonitic in character, form together with basaltic agglomerates the prevailing rocks of the peninsula, whether in the hilly portion or in the plains. They belong to the basic tuffs of mixed composition described on page 330; and though the agency of eruptions can be recognised in their components they are also the products of marine erosion.

Some of the hills represent volcanic "necks"; whilst the low narrow promontory between Kiombo and Soni-soni Island has been formed by an old basaltic flow.

I will begin the description of this peninsula with the eastern extremity north of Kumbulau Point, the interior of which is cut up into ridgy hills 300 to 350 feet in height. On its eastern coast are exposed volcanic agglomerates, composed of large blocks, which from their dimensions given below would weigh between

one-third and two-thirds of a ton, a size indicating the immediate vicinity of the vent, now obliterated, from which they were originally ejected. Near Kumbulau Point the blocks, which are made of basaltic andesite, measure five or six cubic feet. Further north in the vicinity of Vatu-Ndamu, the precipitous coast cliffs are composed of agglomerates, the large blocks of which, often ten cubic feet in dimension, are formed, not of the prevailing basaltic andesites, as in other parts of the peninsula, but of a grey hornblende-andesite. This singular appearance of an acid andesite in a region of basic rocks has no doubt given rise to the native name of Vatu-Ndamu, "the red or brown stone." It belongs to the second order of the hornblende-hypersthene-andesites, and is described on page 298.

Proceeding along the south coast westward from Kumbulau Point, before arriving at the village of Na Tokalau we pass from the district of agglomerates into that of the bedded tufaceous sandstones and clays which are exposed all along the coast to Kiombo about three miles away. The transition is indicated by the agglomerates becoming interstratified with the tuff-beds. These sedimentary tuffs are as a rule steeply inclined at angles of 20 to 40 degrees, the prevailing direction of the dip being to the north-east, its uniformity for such a length of coast being noteworthy. These beds however are occasionally "crumpled"; and here and there a globular structure is developed.

The hills of this region of sedimentary tuffs between Na Tokalau and Kiombo are the highest of the peninsula. They usually attain a height of 400 feet, but do not reach 500 feet. From each of them descends to the coast a spur terminating in a rocky point; whilst between these points lie low sandy flats, where the native villages of Levuka, Kiombo, &c., are situated. The tuff-rocks extend to the top of the hills behind Na Tokalau, and probably this will be found true of most of the other hills. Agglomerates are not common in the district. In the point west of Na Tokalau, however, they are overlaid by basaltic agglomerates, some of the blocks being scoriaceous. In the point east of Levuka, a chocolate-coloured somewhat calcareous tuff-clay occurs interstratified in thin beds with the coarser deposits.

The general characters of these tuff-sandstones and tuff-clays have already been briefly referred to. The former are much more prevalent and non-calcareous; the latter are sometimes a little calcareous and look like marl, and may perhaps contain a few tests of foraminifera. Both are formed of the debris of basic

rocks and are more or less palagonitic. The coarser deposits are described as sample A on page 330. At times these tuffs are composed of much coarser fragments of the same materials, some of them a centimetre in size. A type of tuff intermediate in character is not uncommon.

The promontory that lies between Kiombo and Soni-soni Island has been formed by a remarkable basaltic flow. The low tongue, about 50 feet high and 200 to 300 yards across, in which it terminates, was originally severed by a passage worn by the sea from the main portion; but it is now joined by a low tract only 2 or 3 feet above the beach and partly occupied by mangroves.

The structure of the flow is well exhibited in the shore-flat and coast-cliffs west of Kiombo, and extending to the end of the point. The waves have here cut into its mass and exposed its structure. Its lower part, as exposed in the shore-flat, is made of a compact hemicrystalline basalt; whilst its upper portion, as displayed in the cliffs, 30 or 35 feet in height, is composed of vitreous and semi-vitreous forms of the same rock looking like pitchstone. The upper vitreous part is sometimes massive; but usually it is rubbly, with a tendency to form spheroidal masses. All transitions can there be traced between the hemicrystalline rock of the shore-flat and the vitreous rock of the cliffs.

The rock of the shore-flat, which has a specific gravity of 2·83, is a blackish porphyritic basalt with scanty olivine, and on account of the semi-ophitic character of the augites of the groundmass it is placed in genus 33 of the olivine class. The plagioclase phenocrysts are 3 to 5 mm. in size. About half of the groundmass is made up of felspar-lathes (·17 mm. long) and large augites (·11 mm.), the rest consisting of a smoky devitrified glass containing a few irregular "lacunæ" filled with the residual magma in the form of a reddish-brown opaque palagonite-like material. The rock intermediate between the lower and upper portions of the flow is also intermediate in character, having a specific gravity of 2·77, whilst quite three-fourths of the groundmass are of smoky glass.

The vitreous rocks of the cliffs, though usually rubbly in appearance, have also the aspect in places of brecciated pitchstone tuffs with the interstices filled with waxy palagonite; but the microscopical examination shows that we have not to deal with a rock of detrital origin. We have here the effects of the breaking up and crushing *in situ* of a dark-brown isotropic basic glass¹

¹ The unaltered glass, which incloses a few plagioclase phenocrysts, has a specific gravity of 2·7, and is readily fusible.

carrying porphyritic plagioclase. The interspaces then became partially filled with the finer fragments of the glass and of the crushed felspar; but they were in the main occupied by a still liquid magma which penetrated into the cracks of the glass-fragments and into those of the felspars, where the fractured portions in some cases remained *in position*. There it has become devitrified and often palagonitised. Whether this liquid magma was produced by a partial remelting resulting from the heat developed during the crushing of the glassy upper portion of the flow during the contracting process, or whether it was squeezed upwards from the less consolidated lower portion, I cannot determine, although the last supposition seems more probable. At all events the edges of the glass-fragments are peculiarly eroded as if by the magma. (The bearing of these facts on the origin of palagonite is discussed in Chapter XXIV.)

I infer that this flow has descended from the hills west of Kiombo. Huge masses of agglomerate are exposed in the lower third of the hill marked "470 feet" in the chart, and immediately north of the town. Fine clayey tuffs are exposed in the hill at the back and to the westward of this place; but the locality requires a more detailed examination. The absence to all appearance of vesicular and scoriaceous rocks in the case of this basaltic flow is remarkable. This would not have been expected in the case of a supra-marine flow; and indeed the testimony of the tuffs of this peninsula sufficiently indicates that during their deposition the whole district was submerged.

The future inquirer will doubtless discover some old volcanic "necks" in the hills of this peninsula. One such hill overlooks the Soni-soni inlet about a mile west of Kiombo. It is a singular isolated hill which I have named Bare-poll Peak for descriptive purposes. In my notes its height is stated as 120 feet, but it appeared to me to be rather higher than this. It is capped by two huge masses, 14 or 15 feet high, of a dark grey slightly scoriaceous augite-andesite with a cryptocrystalline groundmass, which apparently form the uppermost portion of a volcanic "neck" or pipe. According to the size of these rock-masses the "neck" would have a circumference of 80 or 90 feet. These masses are in part incrustated with agglomerate.

The adjacent island of Soni-soni, which is almost joined by the mangrove-belt to the adjoining coast, probably represents one of the numerous small vents that were once active in this region. Its single peak is 460 feet in height. As there did not seem much

prospect of finding rocks exposed on its upper part, its slopes being densely covered with tall reeds, my examination was confined to the lower portion during a walk around the island. On its east and north sides occur rocks of much the same character as those exposed in the neighbouring low promontory to the east of it. In addition to agglomerates and basaltic andesites occurred a rubbly pitchstone composed of fragments, up to a centimetre in size, of an opaque brown glass displaying a few phenocrysts of plagioclase and pyroxene, the interstices being filled with crushed fragments of the phenocrysts and finer glass debris. This rock is allied to the "crush-tuffs" described on page 334. It may be added that the basic tuffs are more frequent on the west and south sides of the island.

The low island of Na Vatu in the midst of the Soni-soni inlet is about 250 feet across and only 3 or 4 feet above the ordinary high-tide level. In 1898, when I visited it, this tiny island possessed about 20 houses and a population of 60 or 70 persons, and I gather from Hazlewood's account of these islands that Na Vatu was crowded with houses more than half a century ago. It was apparently in the first place a sand-key, and is protected against the wash of the waves by a low sea-wall formed of large blocks of stone.

An interesting exposure of bedded tuffs and clays is displayed at Ravi-ravi on the west side of the peninsula. A broad shore-flat has been formed by the marine erosion of a line of coast composed of these deposits. The strike is well exhibited, the dip being about 30 degrees N. by W. Here there are alternating beds, a few inches thick, of coarse and fine tufaceous sandstones, sometimes calcareous, with marls or calcareous clays. The mineral fragments of the coarser rocks are composed of plagioclase, augite and rhombic pyroxene, the last being abundant and giving a more acid character to these deposits. The calcareous fragments appear to be principally shell debris. The marl is in part composed of much finer detritus of the same minerals. The other materials of these deposits are derived from the degradation of basic andesitic rocks, and include also a little palagonite. To the westward of Ravi-ravi these beds show signs of disturbance, being steeply tilted to the N.W. Agglomerates also occur in the disturbed area.

The history of the Kumbulau peninsula is evidently the history of the eruptive phases of a number of more or less submerged small vents and of the periods of great marine erosion that

followed during the emergence of this part of the island. The absence or rarity of dykes is remarkable; but most of the hills would represent volcanic "necks" whether of massive rock, tuff, or agglomerate.

THE DISTRICT BETWEEN THE KUMBULAU PENINSULA AND THE YANAWAI RIVER.—Between Nandi Inlet and the village of Rewa the sea-border is low and often swampy, whilst occasional spurs descend from the inland range into the swamps without reaching the coast. Pebbles of "soapstone" (foraminiferous mud-rock) occur in streams and are no doubt derived from the incrusting deposits of the neighbouring hill slopes. In one stream-bed in the swamps is exposed *in situ* a remarkable chocolate-coloured rock that looks like a greasy pitchstone or a palagonite-rock. It is however of detrital origin, and is composed in mass of minute fragments of a basic, sometimes vacuolar, glass in great part converted into palagonite; whilst there are a number of broken crystals of olivine and plagioclase. Through the palagonitic alteration the fragmental character is somewhat obscured, zeolites being extensively developed in the interstices. A little lime occurs and there is a suspicion of foraminifera. The deposit belongs to the group of palagonite marls described on page 335. The deeper rocks of the district are represented in a spur by an altered augite-andesite, originally hemicrystalline and containing much granular epidote.

Proceeding northward from the village of Rewa, one crosses another spur descending from the inland range. It is formed in mass of a dark doleritic olivine-basalt (spec. grav. 2·91) characterised by the length of the felspar-lathes (·28 mm), possessing a little interstitial glass, and referred to genus 25 of the olivine class. It probably represents an ancient flow. Its surface is incrustated, as high as the road ascends, nearly 200 feet above the sea, by fine and coarse palagonite-tuffs; whilst the pebbles of foraminiferous mud-rock in the stream indicate the existence of incrusting marine deposits further up the slopes. The road then leads down into a low-lying undulating district that forms the sea border as far as the mouth of the Yanawai, and reaches about two miles inland without exceeding an elevation of 100 feet, although low hills occur here and there. This region is fronted by mangrove swamps and is traversed by the Matasawalevu and Ndranimako streams. It is a district of basic tuffs and foraminiferous clays, which, as shown below, extend up the slopes of the basaltic Wainunu table-land that lies behind. The soil in all the low country between Rewa and the

Yanawai is red, heavy, wet, and clayey ; and affords a contrast to the dry friable soil of the Kumbulau and Kiombo region to the southward.

The Navakavura plain lying north of Rewa deserves especial mention. It is a low, swampy district which a mile inland is raised only 20 or 30 feet above the sea, and is mostly occupied by casuarina and pandanus trees. Red argillaceous rocks, representing more or less decomposed palagonite coarse and fine tuffs, are exposed in the banks of the streams. Some of them were originally made up of fragments of basic glass which after being palagonitised became much disintegrated. A typical specimen by my side has a soapy feel and looks like a lump of red clay. Microscopical examination shows that it is composed in mass of palagonite, but in an extreme stage of the alteration process.

After traversing the Navakavura plain, one crosses a low hill rather over 100 feet above the sea before descending to Ndranimako. On the hill are exposed reddish clay-rocks, much weathered, but showing vegetable remains and a few univalve and bivalve shells. Extensive submarine deposits occur in the inland district west of Ndranimako. They are the usual foraminiferous clay-rocks or "soapstones," and in places they contain pteropod shells. They are well displayed in river-banks, and in the hill-slopes on either side ; but they are probably of no great thickness since in one locality named Na Savu, nearly two miles west of Ndranimako, the underlying basaltic rock is exposed in the bed of a gully, the sides being of "soapstone." These deposits were formed in comparatively deep water.¹ The greatest elevation at which they were observed was about 100 feet ; but this was as high as I reached in the ascent of the river. According to the natives, who are very observant in such matters, these submarine deposits extend up the slopes of the adjacent Wainunu plateau. On page 86 reference is made to their occurrence on the slopes of this basaltic table-land, $1\frac{1}{2}$ or 2 miles farther north.

In the district between the Ndranimako and the Yanawai rivers basic tuffs and "soapstone" prevail. In this locality, and especially in the vicinity of Ndranimako, siliceous concretions 2 to 3 inches across, occur in places on the surface. Their nature is described in Chapter XXV.

From the foregoing remarks it may be inferred that the sea-

¹ They are described on p. 322.

border between the Kumbulau Peninsula and the Yanawai River is formed of submarine deposits overlying basic rocks which probably represent ancient flows. Some of the deposits are largely formed of glassy erupted materials, which have been converted into palagonite. Others again are more characteristic sedimentary formations accumulated in relatively deep water.

CHAPTER VII

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE NDRANDRAMEA DISTRICT

THIS hilly region of acid andesites is a continuation of the mountainous backbone of the island, being separated from the basaltic mountain of Seatura by the saddle formed by the Na Savu table-land. These acid andesites exhibit in nearly all cases a felsitic groundmass and phenocrysts of plagioclase and rhombic pyroxene; whilst many of them are characterised by brown hornblende more or less pseudomorphosed in the manner described on page 306, and a few display porphyritic quartz. Although these rocks have a common facies, they vary considerably among themselves; and it is difficult to find a term that would strictly include them all. A general description of their characters is given in the chapter on the Acid Andesites.

In this interesting region a number of hills or mountains formed in mass of acid andesites rise up abruptly without any regular arrangement within an area measuring 5 by 6 miles, and elevated 600 to 1,000 feet above the sea. Of these hills, thirteen in all, nine range in height between 1,600 and 2,500 feet above the sea, none of the others rising less than 1,000 feet above that level. But the actual height of each hill above the country at its base is much less than this. The height of the hill-mass, in five or six of the largest, ranges between 900 and 1,200 feet, whilst in the smaller hills it varies between 400 and 800 feet. (See accompanying plan.)

These hills have sometimes a rounded profile, when their summits are usually wooded. Others again terminate in conical bare rocky peaks, either pointed or truncated. They have often precipitous slopes and display vertical cliff-faces high up their sides. Their

VATU-MATA
1,050 feet.

NDRANDRAMEA
1,800 feet.

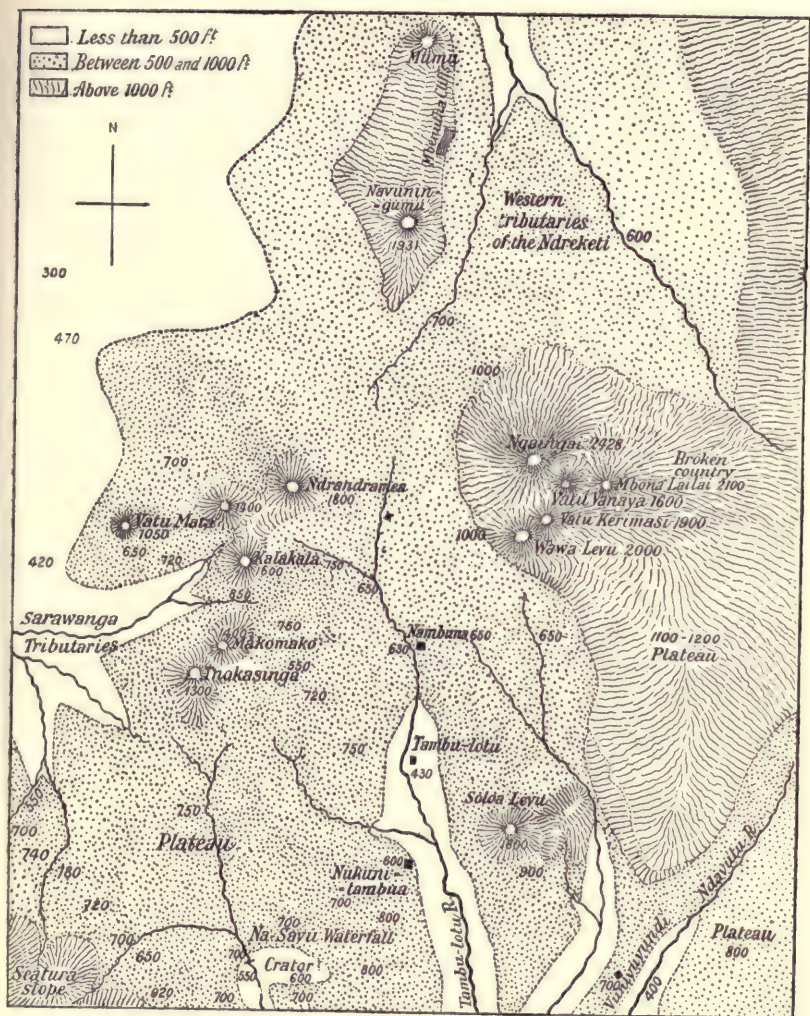
NGAINGAI
2,428 feet.

KALA-KALA
1,600 feet.



The NDRANDRAMEA District from the westward. The hills and mountains are of acid andesites and dacites.
The foreground is elevated about 450 feet above the sea.

arrangement is rather singular. To the south and apart from the others lies Soloa Levu (1,600 feet). Navuningumu (1,930 feet) is similarly isolated on the north. On the east rises Ngaingai (2,430 feet),



Rough plan of the Ndrandrimea district in Vanua Levu; made with prismatic compass and aneroid by H. B. Guppy.

Scale of miles 0 1 2

the highest of the peaks, with Wawa Levu (2,000 feet), Vatu Kerimasi (1,900 feet), Vatu Vanaya (1,600 feet), and Mbona Lailai (2,100 feet) closely clustered by its side. On the west there is

another group of hills, of which Ndrandramea (1,800 feet) is the highest and best known. Associated with it are Kala-Kala (1,600 feet), Mako-mako, Thoka-singa (1,300 feet), Vatu Mata (1,050 feet), and another unnamed peak (1,400 feet) lying west of Ndrandramea.

The districts between and among the hills are much cut up into lesser hills and ridges, the result of the very extensive denudation to which this region has been subjected. The greater part of this area is drained by the Tambu-lotu tributary of the Wainunu; but in the northern part we cross the watershed between the Wainunu and Ndreketi basins, and to reach Navuningumu we cross the valley of one of the tributaries of the Ndreketi. To the east of the Ndrandramea region extends a broken country, elevated rather more than 1,000 feet above the sea, and from it there rise one or two hills with bare cliff-faces, which are probably composed of similar acid andesites.

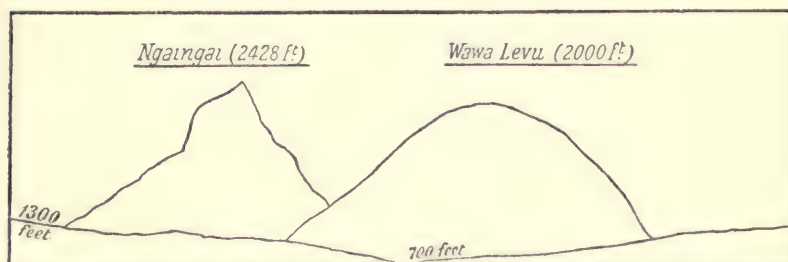
Although for the most part composed of these acid andesites, each hill, as far as my observations show, has as a rule its own type of the rock, differing from the others in specific weight, in the texture of the groundmass, and in the relative proportion of the porphyritic constituents. The petrological characters will be found more fully discussed in Chapter XXI.; and only some of the more distinctive features will be noticed here in the following description of the district.

THE NGAINGAI GROUP OF HILLS.—Within a space less than a mile square rise Ngaingai, Wawa Levu, and the other three hills above named, so closely clustered together that the collective name of "Hen and Chickens" might be aptly applied to the group.

The peculiar form of Ngaingai is shown in the accompanying profile-sketch. It is the Nangorongoro of the Admiralty chart. The height of the mountain from its base is 1,100 to 1,200 feet. Its ascent, which is not difficult, may be made from the west side. Above its wooded slopes rises its bare rocky peak, from which a magnificent panoramic view of the western half of Vanua Levu can be obtained. Characteristic dacites with porphyritic quartz came under my notice all the way up from the foot to the summit, being occasionally exposed in perpendicular cliff-faces. Specimens taken from the upper and lower portions are uniform in character, and have a specific gravity of 2.57. No other rocks were observed on its slopes. The whole hill-mass is in great part if not entirely formed of these acid andesites.

The contrast between the narrow crested peak of Ngaingai and

the dome-shaped summit of Wawa Levu is seen in the sketch; and this is the more remarkable because it is not associated, as far as I could ascertain, with any important difference in geological character. Wawa Levu rises precipitously to a height of 900 or 1,000 feet above its base, and displays often perpendicular cliff-faces on its sides. Its broad level soil-covered summit is mostly covered with young wood, few of the trees having trunks more than 4 inches in diameter, whilst they are usually clothed with damp moss, and are often decayed and rotten.¹ True dacites,



Profiles of Ngaingai and Wawa Levu from Nambuna to the south-west. Both are dacitic mountains.

closely similar to those of the neighbouring Ngaingai and having a specific gravity of 2.61, were displayed often in slab-like blocks from the base to near the top. The rudely columnar structure to be observed in some of the other hills is rarely exhibited. No other rocks came under my notice. The remains of the stone walls of two old "war-towns," one of them named "Ndaku-i-tonga," occur on its south and south-east slopes.

The other three hills of the Ngaingai group were not ascended by me. They show the same bare cliff-faces and have to all appearance the same geological character. Mbona Lailai and Vatu Kerimasi are two blunt-topped conical hills with precipitous slopes that rise respectively about 900 and 700 feet above the country at their base. Vatu Vanaya, about 500 feet in height, has a rounded summit.

THE NDRANDRAMEA GROUP OF HILLS.—A view of these hills from the westward is given in the accompanying illustration. They have a lower elevation than the hills of the Ngaingai group, none of them rising to over 1,800 feet above the sea, whilst their

¹ This absence of a healthy forest-growth, such as occurs on the level summit of the neighbouring Soloa Levu and in all like situations, has probably some geological significance.

height from the base is also less, ranging between 400 and 900 feet. They rise, as the illustration shows, in the midst of a densely-wooded broken country.

Ndrandramea, which is 1,800 feet above the sea, has an individual height of about 900 feet. Fijians in distant parts of the island are familiar with the name of this remarkable peak. It has a legendary fame; and like Wawa Levu in the old time it served as a mountain stronghold in times of war. The remains of a stone-wall of a "koro-ni-valu" or "town of war," known as Mata-meindami-ndami, occur on its side, 300 or 350 feet below its summit; whilst among the wild lemon trees that cover the slopes below large ovoid sling-stones 4 or 5 inches in length may still be found. Viewed from the south-east, as shown in the frontispiece, Ndrandramea has the shape of a woman's breast; and evidently the origin of its name is connected with this resemblance. But seen from the west and south-west, as in the other general view of the district (page 98), it has a broadly truncated conical outline, its form being indeed somewhat elongated or elliptical.

This hill presents precipitous slopes, and on the south side it shows bare rocky faces. As seen in the illustration, it might appear inaccessible; but the ascent is not difficult on the west side. It is composed in mass of an acid andesite allied to the dacites of Ngaingai and Wawa Levu, but differing in the hemicrystalline character of the groundmass (except at the base), in the porphyritic development of rhombic pyroxene, and in the absence of porphyritic quartz. As remarked on page 301, the rock becomes more basic as one descends the hill. At the top its specific weight is 2.44, about 300 feet below it is 2.58, at 700 feet from the top it is 2.68, and at the base of the hill where it is holocrystalline and has a dioritic appearance it is 2.71. That it possesses a rudely columnar structure is shown by the occurrence here and there on the slopes and at the base of the hill of portions of prostrate columns, 3 to 4 feet broad and sometimes 20 to 25 feet long, which have a rounded surface and look like fossil tree-trunks. Masses of agglomerate of the same andesitic rocks lie about in places on the lower slopes, the included blocks, which are a few inches across, being sometimes rounded.

The neighbouring hills lying south and west of Ndrandramea are, as far as my observations show, of the same acid type of andesite. It is connected with those nearest by a saddle, 1,100 feet above the sea, where the same holocrystalline form of the rock occurs, having a specific gravity of 2.7 and being often rudely

columnar in structure. Kala-kala, about 1,600 feet above the sea, is an imposing-looking hill with perpendicular cliff-faces on some of its sides. I did not ascend it, but found at its base a rock of the same andesitic type, differing from that of Ndrandramea in the more crystalline character of the groundmass, and having a specific gravity of 2.61. West of Kala-kala is the outlying hill of Vatu Mata with a flat top and rising only about 400 feet from its base. It has all the appearance of being composed of the same andesitic rocks. It is shown on the left-hand in the illustration.

Lying south of Kala-kala are the two peaks of Mako-mako and Thoka-singa, rising respectively 1,400 and 1,300 feet above the sea. I ascended the last-named, which has a rounded summit covered with trees. Approaching it from Nambuna on the east, I found at its foot a large mass of pitchstone-agglomerate, formed of fragments of vitreous basic rocks, such as occurs around the lower part of Soloa Levu on the other side of the valley. The slopes of Thoka-singa, between 200 and 450 feet below the summit, are strewn with masses of another kind of agglomerate made up of blocks 3 to 8 inches across, occasionally rounded, and composed of the same felsitic andesite, of which the mass of the hill is formed. This last-named rock is exposed in bulk in the upper part, but on the summit the agglomerate reappears. It has a granitoid appearance, and is distinguished from the acid andesites of the other hills of the Ndrandramea district by its greater specific gravity (2.72 to 2.74), by its holocrystalline texture, and by the coarse grain of the mosaic of its felsitic groundmass, which is probably quartz-bearing but is relatively scanty. It is, however, referable to the same group of felsitic andesites, but is to be placed at the basic end of the series. (Its description is given on page 302.) In Thoka-singa we have therefore a hill which is evidently formed in mass of these holocrystalline felsitic andesites but covered in places with an agglomerate of the same materials. I have already referred to this feature in the structure of Ndrandramea. Since the blocks are sometimes rounded, such agglomerates may represent the result of marine erosion during the emergence of this part of the island. In the case of Navuningumu, where they lie abruptly on calcareous clays containing tests of foraminifera and shells of pteropods, a different explanation appears to be needed.

THE HILL OF SOLOA LEVU.—This isolated hill, which presents another type of these acid andesites, has a broad rounded summit; and though elevated about 1,600 feet above the sea, the hill itself rises only 800 or 900 feet above the country at its base,

It is not easy to obtain a view of the profile of this hill and to ascertain its relation to its surroundings; and it was only when I viewed it from near the top of Vatu Kaisia six miles to the eastward that I was able to understand its position. Looking from that standpoint across the basaltic table-land of Wainunu one observed Soloa Levu rising as a dome-shaped hill at the western margin of the table-land and apparently not separated from it. The examination of the district shows that on the east and south-east sides this hill was in part surrounded by the great basaltic flows by which the table-land was built up. Basic tuffs and agglomerates, however, occur on the lower slopes on the north-west, west, and south-west sides, so that Soloa Levu in fact lies in the midst of an area of basic rocks.

The type of acid andesite which is displayed in the upper two-thirds of the hill is distinguished from those of the other hills of the Ndrandramea district by its orthophyric groundmass. Instead of a fine mosaic, the matrix displays as a rule an arrangement of short stout plagioclase prisms; but in one of my slides the two forms of groundmass are associated. In their general characters as described on page 296, they cannot be separated from the acid andesites of the Ndrandramea district. Their specific weight ranges between 2.54 and 2.62, and like most of the other acid andesites they contain little, if any, interstitial glass. Huge blocks of these rocks lie about on the slopes, often assuming a columnar form, the fragments of such columns being sometimes 5 or 6 feet in diameter, and 12 to 15 feet in length. I found one such block standing erect like a solitary obelisk.

The best way to observe the basic rocks that invest the lower slopes of Soloa Levu is to follow the track that skirts it on the south side on the way from Tambu-lotu to Vunivuvundi. Palagonitic tuffs containing in places a little lime¹ and composed of fragments of basic glass of varying size and more or less palagonitised extend from Tambu-lotu and Nuku-ni-tambua (two villages lying about a mile to the westward) to the west and south-west slopes of Soloa Levu. A pitchstone-agglomerate, formed of fragments of a basic glass inclosing large crystals of plagioclase felspar one-third of an inch in length, is associated with these tuffs on the lower north-west, west, and south-west slopes of the hill. The tuffs are formed of the same materials as the pitchstone-agglomerates, but differ in their character of being more or less palagonitised. However, on the north-west side the latter have also undergone

¹ These tuffs are probably submarine. They will be found described with tuffs of the same character on p. 333.

this change. On page 312 will be found a description of the basic glass of these agglomerates in its fresh and in its altered condition. Huge blocks of these rocks strew the surface on the south-west slopes of Soloa Levu, and in one place the underlying acid andesite that forms the mass of the hill is exposed in a stream-course.

These pitchstone-agglomerates and palagonitic pitchstone-tuffs are elevated between 600 and 750 feet above the sea. As one proceeds on the road to Vunivuvundi and skirts the south-east side of the hill one ascends the western border of the basaltic Wainunu table-land which, however, is much cut up by rivers in this locality. Here the tuffs and agglomerates give place to a basaltic andesite, and on reaching an elevation of 1,000 feet we arrive at the top of the table-land from which an ascent of Soloa Levu is easily made. The road then lies on, but parallel to, the border of this plateau for some distance until it descends into a deep valley worn by one of the tributaries of the Wainunu River.

This hill of Soloa Levu is in fact a mass of acid andesite situated in the midst of an area of basic rocks. I found basaltic rocks exposed in the stream courses to the north and similar rocks prevail on the north-west on the way between Nambuna and Tambu-lotu. It has been above remarked that on the east and south it has been in part surrounded by the basaltic flows of the Wainunu table-land, and that pitchstone-tuffs and agglomerates cover its lower slopes on the west and south-west, yet it is not easy to find any trace of the vent from which they flowed or were ejected.

It may be here remarked that the occurrence here and there of basic rocks in the midst of this region suggests the vicinity of dykes. For instance, in a deep gulley about half a mile south-west of Kalakala, where a dacitic rock was exposed *in situ*, I came upon a single large mass of an aphanitic augite-andesite of the type described under genus 16, species A, of the augite-andesites.

THE ALTERED ACID ANDESITES OF THE NDRANDRAMEA DISTRICT.—One of the most important features of the geological structure of this district lies in the fact that the bed-rock exposed in the lower region between the hills is a highly altered acid andesite of the type found in the hills around. By referring to the map of this locality, it will be observed that between the Ndrandrimea hills on the west and the Ngaingai hills on the east is the valley of the Tambu-lotu river and its tributaries, an open broken country deeply eroded by the streams, and elevated 600 to 700 feet above the sea. These altered rocks are well exposed in the deep

gorge-like channel of the river between the village of Nambuna and the foot of Ndrandramea, and in fact in all places in this district where the streams have worn deeply into the surface.

They have a coarse felsitic groundmass, and are described under the felsitic order of the hypersthene-andesites on page 297. They present all degrees of change from the hard dark grey mottled rocks, in which the phenocrysts of plagioclase and rhombic pyroxene are in part replaced by calcitic, viriditic, and chloritic materials, to those where the pseudomorphism and alteration is complete, when the decomposition products give their character to a pale yellowish rock, which sparkles with pyrites and often effervesces briskly with an acid. After this comes the final stage of disintegration, and we get a whitish rotten stone, often full of pyrites, the last condition of which is shown in a kaolin-like material exposed in the river-side.

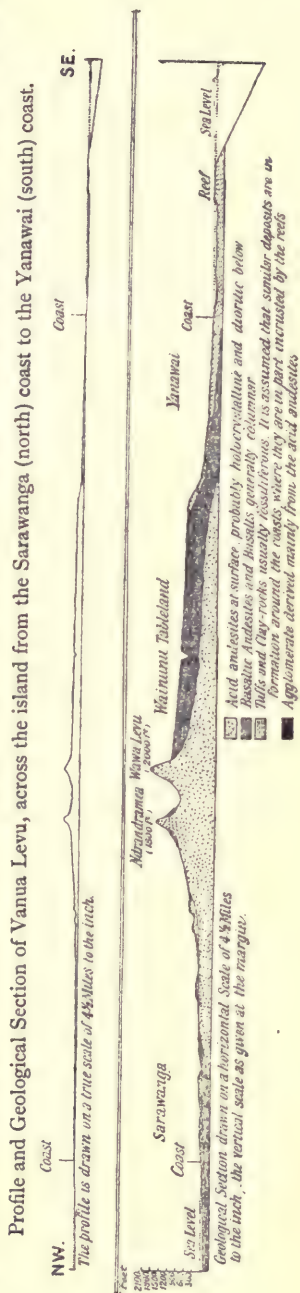
The extensive alteration of these rocks is also indicated by the occurrence amongst the gravel of the river-bed and small stream courses near Nambuna of fragments of clear quartz prisms, half an inch across, and of nodules, three inches in size and sometimes hollow in the centre, formed of radiating quartz crystals that once filled cavities in the altered rock. Small masses of vein-quartz also occur in these streams, formed in a fissure by the growth of the crystals from the sides towards the centre. I was unable to find the source of the quartz; but it is probable that it was produced near the line of contact between the basaltic flows to the eastward and the older felsitic rocks of the district. The great alteration of the acid andesitic rocks exposed as the bed-rocks in this region may in all probability be attributed to the vicinity of these basaltic rocks. The two formations apparently come into contact about a mile east of Nambuna. In traversing this district on the road to Ndrawa one first observes *in situ* in the streams the decomposed felsitic bed-rock with occasional loose blocks of a quartzitic rock that displays in the thin section a mosaic of irregular grains of quartz. Afterwards, as one rises gradually to the top of the basaltic plateau, basaltic rocks are alone exposed in position.

In the character of the fine river sand a clue may be found to the exact locality of the contact. In the midst of the andesitic area between Nambuna and Ndrandramea, the sand, besides containing much magnetic iron, is also composed to a large extent of rhombic pyroxene prisms, clear quartz grains, and fragments of plagioclase, all derived from the porphyritic crystals of the dacites, &c. Near the basaltic district we find that the quartz and rhombic

pyroxene have disappeared, the sand being largely made up of magnetic-iron grains mixed with fragments of plagioclase.

THE EXTENT OF THE AREA OF ACID ANDESITE ROCKS IN THE NDRANDRAMEA DISTRICT.—By referring to the map of this locality it will be observed that this region of andesites extends northward to the Navuningumu Range, and that on the south it would be separated from the district of tuffs and agglomerates, named the table-land of Na Savu, by a line joining the hills of Soloa Levu and Thokasinga. On the east it is bounded by the basaltic area of the Wainunu table-land. On the west it extends at the surface, with an occasional overlying patch of submarine tuffs and clays, for a distance of at least two or three miles from the base of the hills, and sometimes, as in the direction of Sarawanga, more than half way to the coast. I have endeavoured to show the relation of these acid rocks to the basalts and to the sedimentary deposits in the geological section.

When taking the track from Sarawanga to Nambuna by way of Ndrandrimea one soon enters the region of these acid andesites. The prevailing rock exposed on the surface, where it is usually much decomposed, is a bluish-grey hypersthene-andesite with a specific gravity of 2.54, and displaying in a cryptocrystalline groundmass, where the felsitic texture can be recognised, abundant phenocrysts of plagioclase and rhombic pyroxene. As high as 500 feet above the sea it is occasionally capped by patches of palagonitised clays and tuffs scantily foraminiferous, and at one place



I noticed a patch of agglomerate, the subangular blocks six to eight inches across being formed of the same acid andesite. In the same way by taking the road from Tembe-ni-ndio to Nambuna, passing the hill of Kala-kala on the way, we leave behind the foraminiferous tuffs and limestones of the lower coast regions ; and when about 400 feet above the sea we enter the inland district of felsitic andesites which begin about two miles from Tembe-ni-ndio.

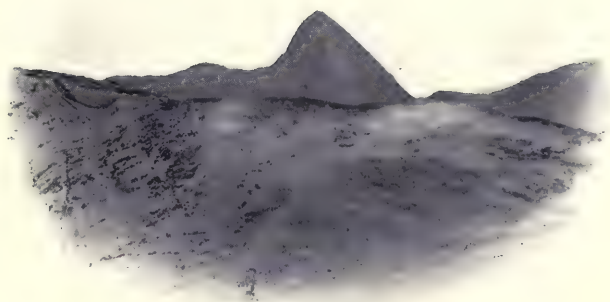
THE NAVUNINGUMU RANGE.—By following the track from Nambuna to Navuningumu one skirts the bases of Wawa Levu and Ngaingai, where dacitic rocks are exposed. After passing the watershed ¹ between the Wainunu and Ndreketi rivers, the track descends into the deep valley of one of the western tributaries of the Ndreketi, where a characteristic holocrystalline type of these felsitic andesites is exposed. Approaching Navuningumu one finds exposed at its base agglomerates, composed of scoriaceous and amygdaloidal semi-vitreous basic rocks, overlying a dark tufaceous sandstone which on examination proves to be a basic pumiceous tuff of the type described on page 333, and scantily foraminiferous.

We stand now in a region of basic rocks on the south-east side of the range, and before us rises abruptly the weird-looking magnetic peak of Navuningumu, which is well represented in the accompanying illustration. In the wet season its summit is usually enveloped in the thunder-clouds. Its elevation above the sea is 1,930 feet, but estimated from its base its height is 1,000 to 1,100 feet. The natives also name this peak Na Seyanga, after a town that once existed in this locality. It is the summit of a range that extends a mile or more to the north where it terminates in a lesser peak known as Mumu.

Ascending the peak of Navuningumu from the south-east one finds exposed in its lower part, up to 1,200 feet above the sea, pitchstone-agglomerates (composed of fragments of a vitreous basic rock) and white tufaceous sandstones (containing a few tests of foraminifera), such as are described below in the case of the neighbouring Mbenutha Cliffs. Between 1,300 and 1,500 feet there is displayed in position a typical dacite of the type described on page 303.

The peak itself is formed of a dark-brown slightly vesicular semi-vitreous basaltic andesite, of which, in fact, for the upper 200 feet, the summit is composed. The rock is somewhat rubbly ; and where it is exposed on the bare peak it is powerfully magnetic,

¹ The track attains an elevation of about 1,300 feet, but the top of the watershed is two or three hundred feet lower.



MT. TAVIA (2,210 feet) from VATU KAISIA. It is probably formed of an acid andesite.



The magnetic peak of NAVUNINGUMU (1,931 feet) from the south.
The summit represents a basaltic neck.

[Face p. 108.]

displaying polarity in a marked degree, and rendering the compass useless (see page 368). A specimen of the magnetic rock, which is a little vesicular, has a specific gravity of 2.82. It is referred to genus 1 of the augite-andesites described on page 267. It displays in the slide porphyritic plagioclase, with a little augite, in a groundmass formed of a plexus of minute felspar-lathes (.06 mm. in length), and exhibiting a large amount of a brown opaque glass in which grains and rods of magnetite with a few pyroxene granules are developed. The magnetite in the groundmass, although abundant, is not in greater quantity than is usually found in semi-vitreous basaltic rocks without polarity. . . . This terminal mass of basic lava-rock evidently forms the "plug" of a volcanic pipe that pierces the acid andesitic rocks of the district; and from this ancient vent were doubtless ejected the basic tuffs and agglomerates that now cover the lower slopes of the mountain.

The conditions under which this volcano displayed its activity are further illustrated in a remarkable section exhibited on the east side of the mountain half a mile or more north of the summit. Here there is a line of bold cliffs, in which, as shown in the illustration, a bed of agglomerate, 60 or 70 feet thick, overlies a series of foraminiferous clays and tufaceous sandstones, which are elevated about 1,100 feet above the sea. The locality is named "Mbenu-tha" or "Rubbish-heap." It is well known to the natives on account of its caves, which serve as a half-way resting-place on the road from Nambuna to Ndreketi. These caves have been produced by the more rapid weathering of the underlying clays and sandstones. The line of cliff extends northward to Mumu, the peak at that end of the range, and preserves there the same structure. The clays and tuff-sandstones are more or less stratified, and dip generally to the west or south-west at an angle perhaps of 20 degrees; but in more than one place they show signs of great disturbance, being contorted and steeply tilted.

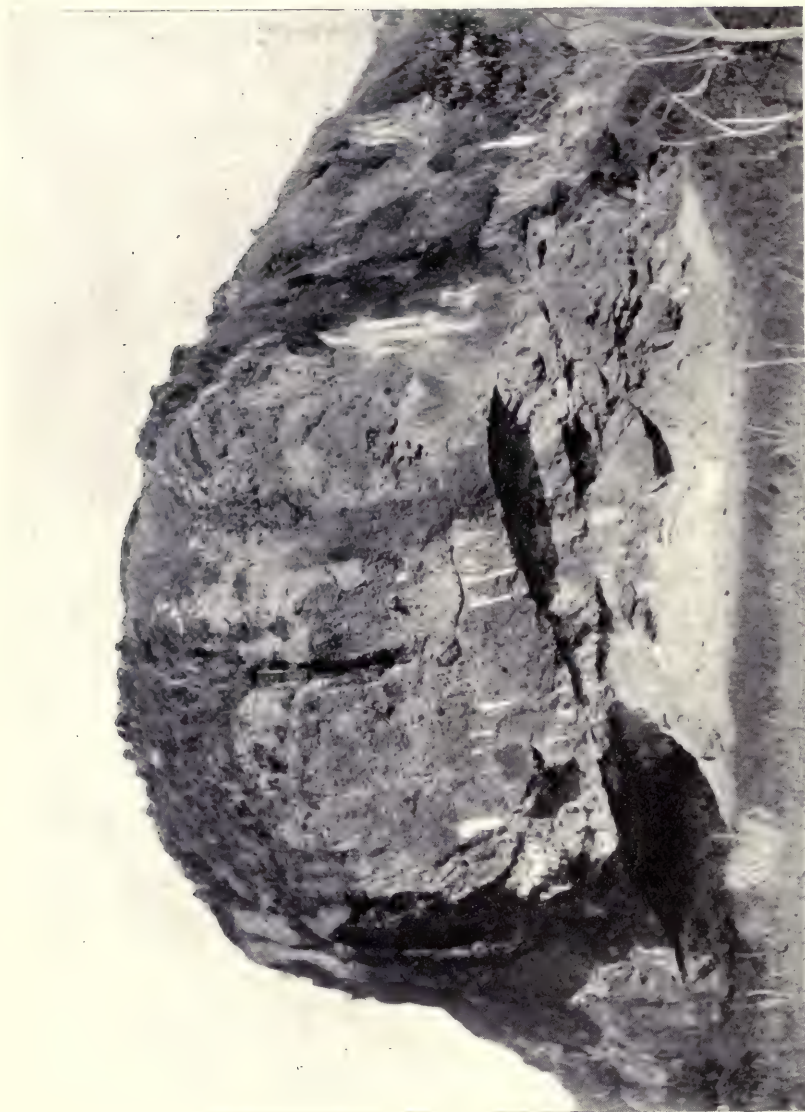
The foraminiferous clays form a more or less compact rock and contain 15 or 16 per cent of lime. They inclose pteropod shells in places and show many minute foraminiferous tests of the pelagic type. Their composition is given on page 323; but it may be here remarked that the residue is made up mainly of palagonitic debris, fine clayey material and minerals. The mineral fragments form about 20 per cent of the mass, and consist principally of glassy plagioclase, with some rhombic pyroxene, and magnetite, their size averaging .1 mm. The tuff-sandstones interstratified with the clays contain only 2 or 3 per cent of lime, and show only a few

scattered microscopic tests of foraminifera. About two-thirds of the rock consist of fragments of a bottle green basic glass, vacuolar and but little altered, the rest being composed chiefly of glass debris, plagioclase, and a little pyroxene, the larger mineral and glass fragments averaging .3 to .5 mm in size. They are in fact submarine hyalomelane tuffs very similar to those first met with at the foot of the mountain, which are referred to on page 108. (They are described on page 333.)

These interbedded clays and tufaceous sandstones of the Mbenu-tha cliffs were deposited under somewhat different conditions. The clays represent the quiet deposition in fairly deep water of fine materials derived from the degradation of acid andesites as well as of basic rocks. The hyalomelane tuff-sandstones were formed more rapidly by the accumulation of fine volcanic ash consisting of fragments of a basic glass ejected from some neighbouring volcano that rose above the sea-surface.

Submarine hyalomelane-tuffs with basic agglomerates appear to be of common occurrence around the base of the Navuningumu mountain. As we leave the range behind and begin to descend the long spur that slopes northward to Ndreketi, we find for the first mile or two these agglomerates. But where the deeper rocks are exposed at an elevation of 600 feet, near the village of Singasinga, there are displayed fine basic pumiceous tuffs and compact palagonitised clays containing little if any lime, the last, however, containing a few casts of microscopic foraminifera. The tuff is made up of minute fragments, the largest less than .1 mm. in size, of a basic hyalomelane glass, which is vacuolar, and often fibrillar like ordinary pumice, and in places shows the early stage of alteration into palagonite. The clay principally consists of more or less palagonitised debris of the same basic glass, together with minute fragments of plagioclase and rhombic pyroxene. These tuffs and clays represent the two conditions of deposition above referred to, the last indicating a period of quiescence when the fine materials resulting from the degradation of both acid and basic andesites were slowly accumulating in deep water, the first denoting the activity of a neighbouring supra-marine vent from which fine dust and ash formed of basic pumice were ejected.

The bed of agglomerate, 60 to 70 feet thick, which overlies the foraminiferous tuffs and clays exposed in the line of cliff extending from Mbenu-tha to Mumu, is made up of subangular blocks, not usually over 6 inches in diameter, of an acid andesite of the general type found in the Ndrandramea region, but possessing a semi-



MBENUTHIA Cliffs showing volcanic agglomerates overlying tuffs and clays, containing shells of pteropods and foraminifera, which are raised 1,100 feet above the sea.

vitreous groundmass.¹ By clambering up the steep slope on the south side of these cliffs, it will be observed that this thick bed of agglomerate is covered by bedded foraminiferous clays and tuffs similar to those that underlie it. It is therefore without doubt submarine, and presents the result of the more violent outbursts of some neighbouring vent. That this vent is now represented by the "plug" of basic lava forming the peak of Navuningumu is highly probable. It is, however, noteworthy that these beds of agglomerates, tuffs, and clays, as shown in the photograph of the cliffs, are all inclined at an angle of 20° towards the axis of eruption or to the westward. The tuffs and clays underlying the agglomerates are, as already remarked, much disturbed in places. It would seem that all the beds here exposed were originally horizontal, and were tilted up during the disturbances accompanying the outbursts of volcanic activity.

The natural section, which the Mbenu-tha cliffs present, is doubtless due to landslips. Similar exposures, displayed by cliffs of basic agglomerate with submarine tuffs and clays at their base, are common on the mountain-slopes of other parts of the island. Water oozes through the underlying soft deposits, and the result is seen in the occurrence of huge masses of agglomerate on the slopes below.

From the details here given respecting Navuningumu and its surroundings, it is apparent that there have been two stages in the history of this volcanic mountain. The first was submarine and was characterised by the discharge of acid lavas which consolidated around the vent and were afterwards covered over with deposits of foraminiferous clays. The second was in the last part supra-marine. With the renewal of activity, the overlying acid andesites were broken through and basic materials were discharged from the new vent. The bed of acid agglomerates exposed in the Mbenu-tha cliff belongs to that period of the second stage when the explosive agencies were most violent. It represents the extensive destruction of the overlying rocks. The foraminiferous tuff-sandstones are submarine accumulations of the finely comminuted fragments of basic pumice that constituted the dust and fine ash discharged from a supra-marine vent. The scoriaceous and amygdaloidal blocks of the basic agglomerates overlying these tuffs around the base of the mountain have had a similar origin. The original ash-cone that at one time rose above the surface of the sea has long

¹ It belongs to the 3rd order of the hornblende-hypersthene-andesites described on p. 299.

since been destroyed by the denuding agencies ; and its situation is alone indicated by the " neck " of basic lava-rock that forms the peak of Navuningumu.

A very long period must have elapsed since this last stage in the activity of the vent. The clays containing pteropod-shells and tests of foraminifera, with which the basic pumice tuffs and the acid agglomerates were interstratified, are now about 1,100 feet above the sea, and are situated in the centre of the island. During the emergence the denudation of the new land-surface was no doubt very great ; and these submarine clays and tuffs, as displayed in the cliffs, owe their preservation in great part to the protection of the overlying mass of agglomerate.

Much light is thrown on the history of the whole Ndrandramea region of acid andesites by the examination of this old volcano of Navuningumu. Some of the hills, as in the case of Ngaingai and Wawa Levu, seem to have been stripped of everything that could give information to the geologist. Others again, like those of Thoka-singa and Ndrandramea, display here and there on their slopes agglomerates of the same materials, the rounded forms of some of the blocks being in part indicative of marine erosion during the emergence of this region from the sea. In Soloa Levu, however, we have one of these hills partially surrounded by later basaltic flows and covered in places on its lower slopes by basic tuffs and agglomerates, probably submarine. In Navuningumu the original mass of acid andesite is only scantily exposed. It is for the most part buried beneath submarine clays which are in their turn covered by the tuffs and agglomerates of later basic eruptions.

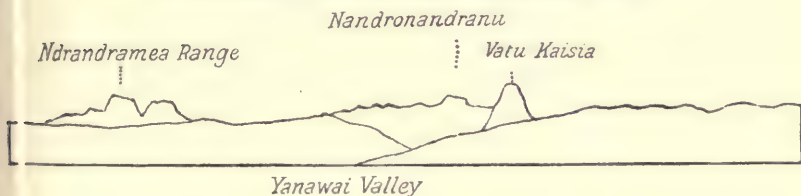
CHAPTER VIII

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

MOUNT VATU KAISIA AND DISTRICT

THIS peak, 1,880 feet in height, starts up suddenly in the mountainous interior of the island. Being situated in the valley of the Yanawai river, which opens to the south, it forms a conspicuous landmark for vessels off the south coast; but from most other points of view, on account of its peculiar situation, it is usually difficult and often impossible to obtain even a glimpse of it.¹ From its remarkable blunt-topped conical shape it has

Profile-sketch of the Vatu Kaisia district from S.S.E.



received the not very appropriate name of Marling Spike in the Admiralty charts. The natives name it Vatu Kaisia, the first word signifying "rock," whilst the second is the name of a demon.

Some idea may be formed of its situation and of the character of the neighbouring country from the profile-sketch and photograph here produced. I was unable for reasons given below to take a photograph of the mountain itself, as it was either too near or too far away. Vatu Kaisia is approached either from Ndrawa on the north or from Ndawara on the south, the ascent being best made

¹ Occasional views of its summit only are obtained from the eastward, as from the Ndrandramea mountains and their vicinity.

from the west side. The regions traversed on the way are so densely wooded that the mountain does not become visible until the traveller is right upon it. He becomes suddenly aware that there is some huge mass close to him looming above his head through the trees; and it is with a feeling of awe that he first looks upon a mountain that although only a few hundred yards away nearly escaped his search. He is startled by its proximity, and wonders what strange forces have been at work to place it there; but his view is transitory, and whether proceeding north or south he sees it no more, unless he essays to climb its slopes.

Vatu Kaisia lies not in the centre but towards the west side of the Yanawai valley the river flowing as an impetuous stream around the foot of its eastern slope. In the profile-sketch the mountain itself conceals the peculiar feature of its position, which is, however, shown in an exaggerated form in the geological section below. On its west side rises a broad ridge running south which in places is not much higher than the basaltic plateau of Wainunu to the west of it. This ridge is only separated from Vatu Kaisia by a dark narrow gorge not many hundred yards in width, across which my natives were able to make themselves heard when near the summit. The mountain rises 1,100 or 1,200 feet above the gorge on its west side, which is 700 feet above the sea, and some 1,400 or 1,500 feet above the Yanawai river on the east, which is 300 or 400 feet above the sea. It possesses two peaks, of which the western one is smaller and lateral and has a height of 1,600 or 1,650 feet, whilst the eastern is the main peak and rises to 1,880 feet. The saddle between the peaks has an elevation of about 1,500 feet. It is very difficult to obtain a distant view of the two peaks, which lie about N.W. and S.E. with each other. They are either merged into one as in the view from the south, or else the highest portion of the main peak is alone visible.

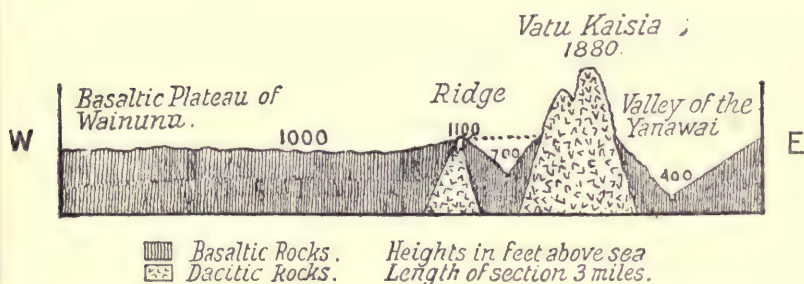
On the lower slopes of the mountain as high as 1,100 or 1,200 feet is exposed a porphyritic doleritic basalt showing semi-ophitic augite and abundant interstitial glass. Its specific gravity is 2.8, but there is no olivine. It belongs to a type of basalt described under genus 9, sub-genus A, of the augite-andesites. The upper double-peaked portion rises precipitously, displaying bare rocky cliff-faces with a drop of 100 or 150 feet, and formed in mass of a grey andesitic rock with a specific gravity of 2.71 and showing abundant small porphyritic crystals of hornblende and rhombic pyroxene. It represents a type of the hornblende-hypersthene-andesites described on page 301. I was unable, through want of

a rope-ladder, to accomplish the last hundred feet of the summit ; but the general uniformity of structure was evident. No detrital rocks came under my observation.

That the porphyritic basalt represents a later flow around this old andesitic mountain is indicated amongst other things by this absence of tuffs and agglomerates. Vatu Kaisia is undoubtedly the core of an ancient cone of hornblende-andesite, and as in the case of Mount Soloa Levu, which is formed of somewhat similar andesites (see page 103), it has been more or less completely surrounded by later basaltic flows. Vatu Kaisia and Soloa Levu occupy similar positions with respect to the great basaltic table-land of Wainunu, the first lying just within its eastern border, the second lying partly within its western margin.

The structure of the ridge immediately west of Vatu Kaisia lends support to this view of the formation of this region. The ridge is here, it is true, elevated a hundred feet or so above the table-land which is about 1,000 feet above the sea ; but whilst on its slopes facing the mountain the same porphyritic basalt prevails, there is a limited exposure on its top of the same rock (sp. gr. 2.68), differing only in the larger size of its porphyritic crystals of hornblende and rhombic pyroxene.

The narrow gorge isolating the mountain on the west is occupied by a tributary of the Yanawai River. It has a depth of 400 feet below the ridge ; and as illustrated in the section below it has



evidently been largely formed by the eroding agency of the stream. However, at the bottom of the gorge there is exposed a heavyphanitic basalt showing no olivine and having a specific gravity of 2.85. Though of much finer texture, the felspar microliths only measuring .05 mm. in length, it differs conspicuously from the overlying porphyritic basalt in possessing little or no interstitial

glass. It is referred to genus 16, species A, sub-species 1, of the augite-andesites (page 280).

The probable structure of this district is shown in the geological section here given. It is assumed from the limited exposure of the same rock on the top of the ridge that the basaltic flows which surrounded the lower portion of Vatu Kaisia at the same time covered over another similar peak lying immediately west of it. Through stream-erosion Vatu Kaisia has now been isolated on its west side; and since the basaltic rocks rise to about the same height on both sides of the gorge thus produced, the original surface was probably as indicated by the dotted line in the diagram.

By following the summit of the ridge, as it runs south on the right side of the Yanawai valley towards Ndawara, some interesting rocks are observed. For the first mile from the camping-place opposite Vatu Kaisia the elevation increased from 1,100 to 1,300 feet, and blocks of a blackish basaltic andesite (sp. gr. 2.76) lay on the ground. About a mile further on fragments of white quartz-rock appeared on the surface having been thrown out of a shaft close to the track which had been sunk to a depth of 15 or 20 feet by a gold miner¹ a few years before. I could not descend the shaft to examine it: but the specimens picked up are evidently a white vein-quartz, some of them having a striated "slickenside" surface on one side.² There is evidently a "contact" in this locality, probably of a basaltic rock with an acid andesite.

Leaving the shaft, the track proceeds southward and eastward, and one descends gradually from a height of 1,100 feet down to the Yanawai river where the elevation is only about 150 feet above the sea. Occasional blocks of basaltic rocks lie on the surface of the ridge, and in one locality there is exposed a curious-looking agglomerate formed of fragments of a greenish altered augite-andesite, somewhat scoriaceous, the cavities being filled with a zeolite. At the crossing of the river a black basalt (sp. gr. 2.82) occurs *in situ*; whilst loose blocks of basalt and of an acid andesite occur in the river-bed. Continuing the journey from the Yanawai crossing to Ndawara near the mouth of the river, one follows the track across a range of hills, 500 to 600 feet in height, basaltic rocks prevailing on the surface.

¹ Alluvial gold has long been known to occur in the bed of the Yanawai below Vatu Kaisia; but it has never been found in paying quantity.

² Under the microscope it is shown to be granular in structure, exhibiting a mosaic of irregular quartz grains.

THE NANDRONANDRANU DISTRICT.

Lying north-west of Vatu Kaisia is an elevated district which I have named after its highest summit, a square-topped peak rather higher than Vatu Kaisia and probably about 2,100 feet above the sea. Koro-ni-yalewa, which signifies "town of the women," is another name of this peak. It is shown in the sketch given on page 113, and is situated about two miles north-west of Vatu Kaisia. I did not ascend this mountain, which from its form would seem to be made of an acid andesite like the Ndrandramea peaks. Much of this elevated region varies between 1,000 and 1,500 feet in elevation. It is connected with the Ndrandramea district by somewhat broken country not much over 1,000 feet in height, which is the "divide" between the river systems of the Ndreketi and Wainunu. A long tongue-like extension of similar elevation projects to the north-west between the Ndrawa and Navuningumu branches of the Ndreketi. This elevated region is continuous to the eastward with the Tavia Range which is described below. For convenience the valleys of the upper course of the Ndrawa river have been included in this district as their geological features can in this connection be best explained.

This region is well distinguished from most of the other districts of the island by the prevalence of aphanitic augite-andesites. These rocks have also supplied the agglomerates of the locality, and the palagonite-tuffs which are in places extensively represented are evidently in great part derived from vitreous forms of the same rocks. We seem to get nearer to supra-marine eruptions in this region than in most others. The palagonitic-tuffs and agglomerates appear to have rapidly accumulated in shallow water, and there is reason for regarding one exposure of the aphanitic augite-andesites as at all events a shallow-water lava-flow. The aphanitic character of the massive rocks, however it may have arisen, is here, as I take it, associated with the shallow-water habit of the tuffs and agglomerates.

(1) EAST SIDE OF THE NANDRONANDRANU DISTRICT.—By following the track leading from the ridge on the west side of Vatu Kaisia northward to Ndrawa one rises gradually to a more elevated region. The rocks exposed on the surface for the first mile are for the most part altered hypersthene-augite-andesites possessing a micro-felsitic groundmass. When a height of about 1,400 feet was attained, the track could not have been far from the peak of

Nandronandranu, but on account of the wood no view was obtainable. In this locality between 1,300 and 1,400 feet soapy palagonitic clay-rocks and coarser palagonite-tuffs are displayed on the surface. No organic remains are to be noticed in the specimens collected here, but they are much affected by hydration. Judging from the fossiliferous character of similar deposits over a large part of the island, it is highly probable that these tuffs and clays are also submarine.

Afterwards a descent was made to an undulating region about $1\frac{1}{2}$ miles across and elevated between 750 and 850 feet. The blocks there displayed on the surface are composed of a dark rather compact augite-andesite with a specific gravity of 2.75 (see genus 13) and of an altered greenish aphanitic augite-andesite with a specific gravity of 2.59 in which calcite occurs as an alteration product (genus 16). Aphanitic rocks of this character as shown below, are very prevalent in the north-west and north parts of the Nandronandranu district, but are not usually altered.

(2) THE NORTH-WEST PART OF THE NANDRONANDRANU DISTRICT.—The best route to follow here is to take the track from Nambuna to Ndrawa. After crossing the upper portion of the Wainunu table-land one reaches the headwaters of the Ndavutu River and then ascends the watershed between the Ndreketi and Wainunu river-systems, reaching Savulu, about 1,050 feet above the sea, where a solitary house marks the site of an old mountain town. This region is much cut up in deep valleys usually 200 to 300 feet deep, which are occupied by affluents of the Ndrawa branch of the Ndreketi, flowing north. The valley of the main affluents is from 400 to 500 feet in depth; and this constant ascent and descent of steep and often slippery valley sides makes the journey very tedious.

At Savulu one stands within the Nandronandranu district. Behind lies the Wainunu table-land with its olivine basalts; but here aphanitic augite-andesites prevail and extend to Ndrawa and beyond. They are exposed in position in the stream-courses and furnish most of the blocks and pebbles found in the bed of the main Ndrawa River for miles down its course towards the sea. They are dark, compact, and non-porphyrific rocks and are all referred to genus 16 of the augite-andesites as described on page 279. They vary, however, in certain features, as in the specific gravity, the amount of glass, &c. The residual glass is, however, usually small; but in a stream-course east of Savulu I found in position at

an elevation of 750 feet a semi-vitreous scoriaceous variety of these rocks, in which the steam-pores had been drawn out into long tubular cavities half an inch and more in length. The scoriaceous character is infrequent; but reference should here be made to another exposure of a slaggy semi-vitreous rock showing abundant steam-pores in the tuff-district of the river valley above Ravuka. It differs in some respects from the prevailing rock, since it displays prismatic augite as well as felspar microliths in its glassy groundmass, and is for this reason referred to genus 20 of the augite-andesites. In the elevated region east of Savulu the aphanitic augite-andesites are in places overlain by tuffs and agglomerates formed of the same materials. There is a very good exposure of the tuffs in the Nganga-turuturu cliffs about 2 miles west of Savulu.

(3) THE NGANGA-TURUTURU CLIFFS.—These picturesque cliffs, 50 to 70 feet in height, rise up at the head of the Liwa-liwa valley between Savulu and Ndrawa. They are elevated about 1,200 feet above the sea; and probably derive their name from a small waterfall which, after descending over their face, drops into the valley below. At its bottom is situated the hamlet of Liwa-liwa, which is about 600 feet above the sea. This is the Fijian word for "cold," and doubtless it has allusion to the coolness of the valley. On account of the more rapid weathering of the tuffs in the lower part of the cliffs, there is a rude shelter afforded by the overhanging portion which is the main feature of interest that the cliffs present from a native's point of view.

The tuffs composing the cliffs are horizontally bedded and overlie the prevailing aphanitic augite-andesite exposed on the valley-slopes below. Originally grey in colour, they have been largely affected by the hydration accompanying the weathering process. They are fine in texture and somewhat friable, but contain no lime, and are chiefly made up of the palagonitised fine detritus of vitreous varieties of the aphanitic augite-andesites of the district. No organic remains came under my notice. Some of the beds contain a number of lapilli of basic pumice, 1 to 3 centimetres in size, which are often in the last stage of the disintegration produced during palagonitisation. It would seem probable that these lapilli, after having been ejected from some supra-marine vent, were deposited with the tuffs in the sea around. It should, however, be not forgotten that vesicular and pumiceous materials may be discharged during a submarine eruption. When I visited the museum at Catania, Prof. Platania showed me portions of a bomb,

highly vesicular, that had been thrown up in a submarine eruption off Vulcano in the Lipari Islands.

(4) THE UPPER VALLEYS OF THE NDRAWA RIVER.—The two valleys of Liwa-liwa and Ndrawa meet at Ravuka, where their two streams unite to form the main Ndrawa River. The former is the largest; and its large impetuous stream, during its descent of about two miles from Liwa-liwa past Lutu-kina to Ravuka, which is between 200 and 250 feet above the sea, has a drop of 300 or 350 feet. The main stream flows with a gentle gradient to the coast about ten miles away. I did not descend its course for more than two miles below Ravuka, where some hot springs well up through the gravel on the left bank (see page 31.)

This is a region of palagonite-tuffs which like those of the Nganga-turuturu cliffs are mainly derived from vitreous and semi-vitreous aphanitic augite-andesites. They do not effervesce with an acid, and neither foraminiferous tests nor other organic remains occur. The palagonitic material is usually vacuolar, the vacuoles being filled with palagonitic glass or with a zeolite as in the more altered rocks. Where bedding is shown, the beds are generally horizontal. These tuffs are extensively displayed in the sides and beds of the rivers from Liwa-liwa and Ndrawa to Ravuka and as far as I went down the main river, namely to the hot springs. They are associated with agglomerates, formed of the aphanitic augite-andesites, below Ravuka and in the Ndrawa valley.

(5) THE VICINITY OF NDRAWA.—The village of Ndrawa, which is not elevated more than 300 feet above the sea, is situated in the heart of the island in a deep valley more or less hemmed in by the mountains. This is one of the wettest localities in Vanua Levu, and probably, as in the case of that of Ndriti in the Seatura basin, the rainfall is not far under 300 inches in the year. In the river-gorge descending westward to Ravuka are displayed horizontally bedded palagonite-tuffs and agglomerates above referred to in the description of the Ravuka district, and the same rocks are exposed on the mountain-slopes to the south of the village.¹

Immediately to the north lies a broken hilly country, about 800 feet above the sea, which has to be crossed on the way to Mbatiri and is much cut up by streams descending from the vicinity of Na Raro to join the Ndrawa River below Ravuka. The prevailing rocks are tuff-breccias and agglomerates. The first are made up chiefly of angular fragments, less than an inch in size, of aphanitic

¹ The blocks of the agglomerate in this last locality are from one to three feet across.

augite-andesites, some of them being more or less vitreous and in different stages of palagonitisation, whilst the finer material derived from the same rocks contains some carbonate of lime. The agglomerates are composed of the same type of these augite-andesites, with however but little interstitial glass. It should be added that pebbles of a kind of jasper or iron-flint occur in the stream-beds in this locality. (The microscopical characters are described on page 355.)

By following up the valley that extends to the east from Ndrawa, one enters after about a mile into the region of Na Raro, which is described on page 123.

THE TAVIA RANGES.

North of Vatu Kaisia the elevated Nandronadranu district divides into two ranges, one of which stretches eastward to the south of Na Raro as far as the gap of that name, whilst the other extends southward on the east side of the Yanawai valley. Near the angle of bifurcation is situated Mount Tavia, a remarkable pyramidal peak marked 2,210 feet in the Admiralty chart and lying $1\frac{1}{2}$ miles north-east ($N33^{\circ}E$) of Vatu Kaisia. It is shown in the view facing page 108. All this region is densely wooded, and I had chiefly to rely on "course-and-distance," and on my aneroid, to determine the surface-configuration.

(1) RANGE ON THE EAST SIDE OF THE YANAWAI VALLEY.—No ascent of these hills was made. They vary from 1,500 to 1,800 feet in height, and judging from the loose blocks and gravel in the bed of the Yanawai River below Vatu Kaisia they would seem to be mainly formed of basaltic rocks, acid andesites being also represented. However, I crossed the southern end of the range, where it is 500 to 600 feet in height, to the north of Ndrawa, and found basaltic andesites prevailing at the surface.

(2) RANGE EXTENDING EASTWARD FROM MOUNT TAVIA ON THE SOUTH SIDE OF NA RARO.—Mount Tavia, which has the appearance of a dacitic peak, was not ascended; but the range was crossed in two places in going from Ndrawa to Vatu-vono and from Valeni to Nareilangi, its usual height varying between 1,200 and 1,500 feet, the extreme height being about 1,700 feet.

In making the traverse from Ndrawa to Vatu-vono, one first passes through a part of the hornblende-andesite region of Na Raro, which is described in a later page. Afterwards while ascend-

ing the north slopes of the range, basaltic andesites, often doleritic in texture and referred to genus 1 of the augite-andesites, are usually found as far as the summit 1,200 to 1,300 feet above the sea. On descending the south slopes one finds coarse and fine palagonite-tuffs and clays at 900 to 1,100 feet up, similar to those prevailing near the sea-border. They are probably submarine, but my specimens are weathered and give no effervescence with an acid. In the bed of the river above Vatu-vono, about 400 feet above the sea, there occurs in position an aphanitic augite-andesite (spec. grav. 2.77), referred to genus 16, species A; whilst blocks of a coarser grained basaltic andesite lie loose in the stream.

In my traverse across the range from Valeni to Nareilangi I noticed about a mile from Valeni and not much over 100 feet above the sea an agglomerate formed of blocks of an altered acid andesite possessing a micro-felsitic groundmass and showing micro-porphyrific rhombic pyroxene with dark alteration borders (spec. grav. 2.5). It is distinct from the Na Raro rocks; and its presence in an agglomerate seems to indicate the vicinity of some old acid andesite peak buried beneath later basic eruptive products. Ascending the south slopes of the range, I found decomposing basaltic andesites and basic tuffs, the prevailing rocks up to an elevation of 1,300 feet; but in one locality (800 feet) occurred large masses of what seemed to be a disintegrating dacitic rock penetrated by quartz veins less than an inch thick. An aphanitic augite-andesite, of a somewhat exceptional character (spec. grav. 2.63), was displayed at the top of the ridge, 1,500 feet above the sea.¹ Basic rocks were exposed in the spur running northward on the east side of Na Raro.

THE SEA-BORDER EXTENDING EAST FROM THE YANAWAI RIVER TO THE LANGO-LANGO RIVER.—In this district is included the area between the foot of the slopes of the Tavia Ranges and the shores of Savu-savu Bay. This undulating country, two to three miles in breadth, does not attain a greater elevation inland than 300 or 400 feet. Fine and coarse palagonite-tuffs, some of them with the texture of sandstone, are the characteristic rocks. They at times contain a little lime and probably a few tests of foraminifera. The palagonitised glass is often vacuolar, the vacuoles being filled with the same material. In places where they are well displayed these tuffs generally show bedding, as in a hill-slope just east of Vuni-evu-evu, where there are fine and coarse tuffs inter-

¹ It displays in the groundmass augite prisms in flow-arrangement, and is referred to genus 20 of the augite-andesites.

stratified and dipping gently W. by S. Basic agglomerates also occur in this district.

In the promontory named Yanutha Point in the map there is displayed an old flow of basaltic lava, showing a columnar structure at the end of the point. The columns are 20 inches in diameter, and are inclined about 20 degrees from the vertical in such a direction that it may be inferred that the original flow, doubtless submarine, descended at that angle from N.N.W. The dark grey rock of the columns (spec. grav. 2.76) has a fair amount of interstitial glass, whilst a blackish compact rock (spec. grav. 2.78) that represents apparently a more superficial part of the flow has an abundance of smoky glass in the groundmass. These rocks are basaltic andesites and are neither vesicular nor scoriaceous, and come near the basalts of the Kiombo flow which, however, contain some olivine (see page 92). They are semi-ophitic and are referred to genus 21 of the augite-andesites which is described on page 283.

NA RARO.

In Na Raro we have one of the most interesting of the isolated hornblende-andesite mountains of Vanua Levu. Unlike Vatu Kaisia, which often eludes the observation, Na Raro is visible from most points of view. It is double-peaked, the two peaks lying in a north and south line and rising precipitously. It is this feature that gives the mountain such a variety in its profile. From the north and south it appears as shown in the accompanying sketch as a sharp conical peak. From the north-east and south-east, as illustrated in the two other sketches, it has the form of a blunt or square-topped mountain; and its true shape is only shown when it is seen from the east or west. In the photograph here reproduced which was taken about $1\frac{1}{2}$ miles to the south-west, the two peaks are with difficulty distinguished. (See frontispiece.)

Not many ascents have been made of these precipitous peaks. Mr. A. Barrack, who kindly supplied me with some information about it, made the ascent some years ago; and Mr. Blyth (?), a magistrate, also reached the top. There are stories of some big officials being hauled up in baskets; and the natives told me of a white man who was seized with a shivering-fit when he arrived at the summit. It is certainly a rather hazardous climb; but the safest plan is to resign oneself into the hands of the natives, who "bundle" one up in an expeditious, if not in a very ceremonious, fashion. Nareilangi, near the foot of the mountain on the north

side, is a convenient starting-point, and half a dozen stout Fijians will not prove too many to assist the climber in the difficult parts of the ascent. Since the top usually becomes clouded as the day progresses, it is best to spend a night in a cave about 1,400 feet

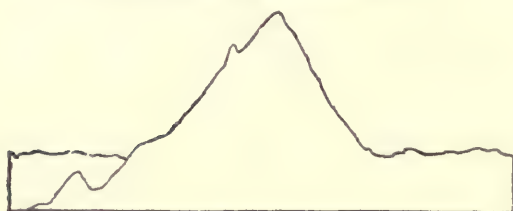
PROFILES OF NA RARO.

Na Raro (2420)

Tavia Range (1200-1500)



From the south off Kumbulau Point.



From the north in the Ndreketi Plains.



From the North-east.



From the East-south-east.

above the sea from which the ascent can be made in the early morning. The view from Na Raro is panoramic and extends over a large part of the island from Naivaka to Savu-savu.

Na Raro rises up to a height of 2,420 feet in the midst of a region of basic rocks. Agglomerates and coarse tuffs formed of aphanitic augite-andesites prevail in the broken country on the north and west sides towards Nareilangi and Ndrawa. Immediately south rises the Tavia Range with its basaltic andesites and overlying palagonite-tuffs; whilst on the east lies a spur of this range.

Nareilangi, the village from which the start is made, is about

2½ miles distant from Na Raro, and though situated in the heart of the island it is only about 100 feet above the sea. The track first passes through a district of foraminiferous tuffs and clays reaching up to 200 or 250 feet. Afterwards a broken country extending up to 800 feet is traversed. Here prevail agglomerates and tuff-agglomerates derived from aphanitic augite-andesites.¹ One then descends into a valley about 600 feet above the sea, and from this place the ascent of the mountain proper begins.

The ascent at first is fairly steep, dacitic tuffs prevailing up to 1,000 or 1,100 feet above the sea and forming in places precipitous cliff-faces. Large masses of hornblende-andesite lie on the slopes. The dacitic tuffs distinguish Na Raro from all the other peaks of hornblende-hypersthene-andesite rocks that I examined. They seem generally to have been stripped off by the denuding agencies; and only at times, as around the slopes of Ndrandramea and Thokasinga, are to be found the remains of agglomerates of the same formation. In the case of Na Raro, however, the tuffs differ somewhat in their components from the rocks forming the mountain mass. The tuffs are derived from a hornblende-andesite of dacitic type; whilst the massive rocks of the mountain are of hornblende-hypersthene-andesites, without porphyritic quartz, but approaching the dacitic habit.

The tuffs of Na Raro, which are sometimes compacted and at other times rather friable, do not display bedding. They contain a little lime; but I found no tests of foraminifera. They are composed of fragments, up to a centimetre in size, of a dacite displaying brown hornblende, plagioclase, and quartz in a microfelsitic groundmass, together with a few fragments of a semi-vitreous basic andesite.

Above 1,100 feet the tuffs give place to the massive hornblende-hypersthene-andesite. At an elevation of 1,450 feet, a shoulder of the mountain is reached, near the top of which is the cave above mentioned. Crossing the shoulder one descends for 100 or 150 feet into a gap, thus reaching the foot of the precipitous northern peak, which rises up like a wall for a height of from 900 to 1000 feet overhead. It is in mass of the andesite just mentioned, many of its faces presenting inaccessible cliffs displaying seemingly no structure. This peak is somewhat lower than the southern peak. I placed its height at 2,270 feet, which, taking the total elevation of the mountain at 2,420 feet, as given in the chart, makes the difference 150 feet. A deep and broad cleft, that goes half-way

¹ Referred to genera 16 and 20 of the augite-andesites.

down the mountain, separates the two peaks. The southern one, which appears to be inaccessible, is evidently formed of the same acid andesite.

These hornblende-andesites, with or without porphyritic quartz, appear to be for the most part restricted to the immediate vicinity of Na Raro, except to the south-west, where at a distance of about a mile and a half from the mountain at an elevation of 500 feet occur a rubbly hornblende-andesite and agglomerates of the same materials. Though the rock is of the Na Raro type, its presence here is suggestive of a distinct vent of small size, of which most of the traces have been swept away during the emergence of the island. About half a mile south-east of this locality at an elevation of 450 feet occur some singular banded palagonite-tuffs which, although they do not show foraminifera in the section examined, contain a little calcite and are probably of submarine origin. . . . In this locality I found a large white mass, measuring $4 \times 4 \times 5$ feet, formed of a siliceous rock appearing in thin sections as granular chalcedonic quartz (see page 355).

The hornblende-andesite of Na Raro, as in the case of the rocks of most of the other peaks of acid andesites, has its peculiar characters. It differs, for instance, from that of Vatu Kaisia in the larger grain of the felsitic groundmass (N. R. .021 mm. ; V. K. .013 mm.), in the absence or rarity of phenocrysts of rhombic pyroxene, in its lower specific gravity (2.6 N. R. : 2.7 V. K.), in the presence of a little interstitial glass, and in other particulars. Both, however, belong to the sub-class of hornblende-hypersthene-andesites, and are described on page 301. In the Na Raro rock the rhombic pyroxene is represented in the groundmass.

With regard to the relative age of Na Raro I am inclined to think that it is the most recent of the acid andesite peaks of the island. Neither vitreous nor vesicular rocks came under my notice in its vicinity ; whilst the tuffs that clothe its lower slopes are non-pumiceous, though of dacitic origin, but containing also a few fragments of a semivitreous basic andesite showing tiny felspar lathes and augite-granules. Since the everywhere prevailing submarine palagonite-tuffs and foraminiferous clays do not extend over its area, we may assign to it a later date. It is evidently also posterior in time to the basaltic andesites and aphanitic augite-andesites around, which are covered by these submarine deposits. Relatively recent as it apparently is, this mountain bears the impress of a high antiquity. There is nothing to indicate that this "core" of a volcanic mountain belonged to a

subaerial vent. Na Raro has shared in all the later stages of the submergence and emergence of the island. Though it presents the final page in the history of the hornblende-andesite volcanoes, that chapter has been for unknown ages closed.

THE NA RARO GAP.—Between the Tavia and Va-lili Ranges there is a break in the mountainous backbone of the island, to which I have given this name. The greatest elevation is probably not over 800 feet. It is from the south side of this watershed that the Lango-lango river takes its rise.

CHAPTER IX

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE BASALTIC LOWLANDS OF SARAWANGA AND NDREKETI.

ONE of the most striking features of the north side of the island is the extensive undulating plain that stretches from the Lekutu river to near Sealevu on the head-waters of the Ndreketi, a distance of almost 30 miles. In its western half this plain slopes gradually to the sea-coast, where it is bordered by a broad belt of mangroves. In its eastern half, from the mouth of the Ndreketi eastward, the lofty Nawavi coast range intervenes between it and the sea-shore. Its breadth varies usually between 4 and 6 miles, and its elevation, though it reaches a maximum of about 300 feet, is as a rule between 100 and 200 feet above the sea.

Over nearly all its area it presents the dried-up and scantily vegetated appearance of the "talasinga" regions. It is an open country mostly clear of forest; and it is to this character as well as to its peculiar vegetation that it in some measure owes its barren look. Amongst the bracken, grass, and tall reeds (*Eulalia japonica*) that clothe much of its surface flourish the *Pandanus*, the *Casuarina*, and the Cycad, which give a special physiognomy to the whole area; whilst several sea-side plants, as *Ipomea pes capræ*, *Morinda citrifolia*, *Cerbera odollam*, &c., have spread themselves far and wide over its extent. It is traversed by the rivers Ndreketi, Sarawanga, and Lekutu, the two first named being navigable for several miles, as the tide ascends a long way from the coast.

In its essential characters this region corresponds with the Mbua and Ndama plains at the west end of the island, which have been previously described. Wherever the rivers have worn channels of any depth, basaltic rocks, sometimes columnar in structure, are exposed; and over most of its surface the same rocks

are displayed, often much decomposed and developing a spheroidal character, or lying in large blocks all around. Overlying the basaltic rocks in various localities occur foraminiferous clays and other submarine deposits. This great region of plains is partially divided into two by the projecting mass of the dacitic district of Ndrandramea, the slopes of which descend to within 3 or 4 miles of the coast between the Sarawanga and Ndreketi rivers. For convenience of description I will deal with these two sub-regions separately under the names of the Sarawanga and Ndreketi plains.

THE BASALTIC PLAINS OF SARAWANGA.—These plains extend about 6 miles inland to the village of Tembe-ni-ndio on the headwaters of the Sarawanga river. The prevailing type of basalt in this region is a porphyritic olivine-basalt showing a few large crystals of glassy plagioclase and having a specific gravity of 2.84 to 2.9. They are neither vesicular nor scoriaceous and are referred to genera 25 and 37 of the olivine class. The felspar-lathes of the groundmass average .2 mm. in length, and there is a little interstitial glass. They cannot often be distinguished in their characters from the olivine-basalt displayed in vertical columns, 4 to 5 feet in diameter, on the lower slopes of Seatura at the back of Tembe-ni-ndio (page 63). It is highly probable that most of the basalts of these plains belong to lava-flows that descended from the great Seatura vent. In the lowlands it is much decomposed, and a spheroidal structure is frequently developed during the disintegrating process, just as has been noticed in the case of the Mbua and Ndama plains on the west side of Seatura. The rounded blocks that commonly occur on the surface may be regarded in each instance as the nucleus of a weathering spheroidal mass. When this rock is exposed unaltered in the streams it is usually massive or non-columnar.

There is a less common type of basalt in this region which perhaps may represent the upper portion of these basaltic flows. I found it exposed in the bed of the Selesele river about half-way between Lekutu and Sarawanga and about 2 miles inland, where it formed vertical columns $1\frac{1}{2}$ feet across. It differs principally in the presence of a few small amygdules and in the greater amount of interstitial glass. The columnar basalt that Dana in the "Geology of the United States Exploring Expedition" describes as occurring at the mouth of the same river probably belongs to the same flow. He remarks that a few hundred yards back from the "Watering-place" there is an exposure of columnar basalt, the columns being vertical, 1 to $2\frac{1}{2}$ feet in diameter, and usually six-sided.

The incrusting submarine deposits found in patches over these plains are generally calcareous clay-rocks containing tests of foraminifera and often also univalve, bivalve, and pteropod shells. They are referred to the foraminiferous mud-rocks described on page 321. Such deposits are properly dark-coloured; but as exposed at and near the surface they have often lost by hydration most of their lime, and have acquired by the removal of the iron oxides a whitish or pale-yellow appearance, whilst they have a peculiar soapy "feel," on account of which they are generally known as "soapstone" amongst the whites. Streams flowing through such districts have a somewhat milky colour. These deposits are extensively represented on the slopes of the Sarawanga valley, and especially to the east of the town of that name. They are well displayed on the way from Sarawanga to Tembe-ni-ndio, and are also to be seen on the surface of the plains between Lekutu and the Mbua-Lekutu watershed to the southward.

In the vicinity of Sarawanga they attain an elevation of 200 feet above the sea; but they may be traced in patches up to 500 feet on the adjacent slopes of the acid andesite region of Ndrandramea. Near the river, and less than 100 feet above the sea, these deposits are in one place overlain by an agglomerate formed of large blocks, 1 to 2 feet across, of these Ndrandramea andesites and dacites. In another place, near the town of Sarawanga, I found them exposed in the river-bank, where they were covered over by a coarse palagonitic bedded tuff, dipping gently eastward and somewhat calcareous. From the character of the shells of marine univalves inclosed in this tuff, it appears to have been formed in shallow water.

A very interesting display of these surface marine deposits occurs in the upper part of the Sarawanga valley in the vicinity of Tembe-ni-ndio. Here we have fine and coarse calcareous palagonitic tuffs, containing tests of foraminifera, associated with impure foraminiferal limestones. They occur up to elevations of 300 feet above the sea on either side of the Sarawanga valley above this town, incrusting on the north side the lower dacitic slopes of the Ndrandramea district, and on the south side the lower basaltic slopes of Seatara. At the bottom of the valley, as in the rising ground between Tavua and Tembe-ni-ndio, they conceal in part the basaltic rocks of the district.

Near the last-named place, on the right bank of the Tembe-ni-ndio branch of the Sarawanga river, the foraminiferal limestones are displayed in low cliffs 15 to 20 feet in height. They are some-

times earthy when they contain about 25 per cent. of lime, and at other times more compact with about 45 per cent. of lime, the residue being composed of palagonitic materials, tiny fragments of minerals and of a basic rock, &c.¹ Large shells of *Ostræa* and *Cardium* are also contained in these limestones, the valves being detached from each other. The oyster shells project from the weathered surface; and it is probable that the name of Tembe-ni-ndio, which signifies "the shell of the oyster," may be thus explained. Underneath the foraminiferal limestones in this locality occur bedded coarse tufaceous sandstones, slightly inclined E.N.E., and inclosing waterworn gravel and pebbles. These low limestone cliffs, although about six miles inland, are not more than 120 or 130 feet above the sea. In their face there is evidence of an old erosion-line of the river 10 or 11 feet above its present level.

By following up this branch of the river for a little distance I came upon an exposure of nearly horizontal bedded palagonitic tuffs on its floor and sides. Here a coarse tuff, of which the larger fragments composing it range between 3 and 5 mm. in size, passes upward into a chocolate-coloured compact tuff-clay formed of the same materials, the larger averaging .2 or .3 mm. in size. These tuffs are made up chiefly of a palagonitised vacuolar basic glass, the vacuoles being filled with the alteration products. The lower coarse tuffs contain very little lime, probably not over 1 per cent., and exhibit no organic remains in the slide. The upper fine tuffs have 3 or 4 per cent. of lime, and inclose numerous minute tests of foraminifera of the globigerina type, their cavities being generally filled with palagonitic material.

Further up the valley about a mile above Tembe-ni-ndio, and about 250 feet above the sea, the impure foraminiferal limestones again appear; but they here exhibit an important difference in texture. In the groundmass of those of the lower locality, the calcite is granular and loosely arranged, or displays in an obscurely indicated mosaic the commencement of recrystallization. In the case of those of the upper locality the calcitic material of the groundmass has more completely recrystallized, and shows a fairly clear mosaic; whilst in one place the rock was overlain or rather incrustated above by a layer, 3 inches thick, of a white crystalline limestone, looking like statuary marble, and inclosing portions of a material like that of the rock beneath it. This last, when examined in the slide, exhibits itself as formed in mass of crystalline calcite, displaying a regular mosaic, and inclosing small fragments

¹ These foraminiferal limestones are described on p. 319.

of palagonitised materials and of minerals (pyroxene) such as are abundant in the rock below. In places the grains of the mosaic are bordered by brown and black iron oxide. It would, therefore, appear that a metamorphism has been in operation here, and that the process which began with the recrystallization of the matrix in the lower rock is almost completed in the overlying thin layer where even most of the non-calcareous materials have disappeared. No evidence suggestive of contact-metamorphism came under my notice in this locality. These foraminiferal limestones are surface formations, and it was in the uppermost portion that the metamorphism was most complete. We here witness in operation the transformation of a rock containing 46 per cent. of carbonate of lime (the residue of minerals, palagonite, &c.), into a marble or crystalline limestone. I gather that as in the instance of several of our old British limestones the change is a purely interstitial one, and is not connected with thermal metamorphism.

These remarks on the basaltic plains of Sarawanga and on their incrusting submarine deposits may be concluded with a brief reference to the siliceous concretions, 2 or 3 inches across, the silicified portions of corals, and the fragments of clay iron-stone and limonite resembling hæmatite, that occur frequently on the surface. They are common on the plains south of Lekutu and between Lekutu and Sarawanga, and up to elevations of 200 feet in the foraminiferous clay district east of Sarawanga, where fragments looking like portions of the silicified branches of Madreporæ are to be found; but they are not limited to such localities, and may occur also where the surface is formed of decomposed basaltic rock. (These matters are generally discussed in Chapter XXV.)

THE BASALTIC PLAINS OF THE NDREKETI.—This low-lying region of rolling "talasinga" country now serves as the basin of the Ndreketi river, the largest of the rivers of Vanua Levu. It is usually elevated between 100 and 300 feet above the sea, and its limits are well defined by the 300 feet contour line in the map of the island. On the east it is separated from the basin common to the Wailevu and Lambasa rivers by the Sealevu Divide, which is described on p. 136. On the west, as before observed, it is only in part distinguished from the basin of the Sarawanga by the spur descending from the dacitic mountains of Ndrandramea. It meets the coast in the vicinity of the mouth of the Ndreketi; but for two-thirds of its length it is cut off from the sea by the great Nawavi range. It supports the characteristic vegetation of the "talasinga" or sun-burnt land. Whilst the Pandanus and the

Casuarina are most conspicuous amongst the trees, bushes, herbs, grasses and ferns predominate. Here the native Ginger and the native Turmeric with species of *Tacca* are frequently to be recognised, and the waste-land bushes of *Dodonaea viscosa* and *Mussaenda frondosa* are abundantly to be found.

As in the Sarawanga plains, the basaltic rocks are here often overlain or incrustated by submarine deposits, the former exposed in all the deeper river-beds, the latter frequently displayed in the sides of their tributaries.

I will deal first with the basaltic rocks. In the places where the surface deposits have been stripped off, these rocks are generally exposed as decomposing boulders, the spheroidal structure being well developed in the weathering process. Not infrequently, however, a rudely columnar structure is exhibited where the rivers have cut deeply into the basalt. The columns that I observed were usually vertical. In the river-bed at the landing-place at Mbatiri, for instance, the columns are from $2\frac{1}{2}$ to 3 feet across and vertical. As exposed in the river-crossing about a mile above this town they are 12 to 15 inches in diameter and also vertical. However, at Na Kalou, a coast village about $1\frac{1}{2}$ miles east of the mouth of the Ndreketi, where there is an unexpected exposure of basalt, the columns, about a foot in diameter, are inclined at an angle of about 20° from the vertical and face to the north.

These rocks are, as a rule, compact, only showing a typical scoriaceous structure in the case of specimens obtained near the foot of Nakambuta, an isolated hill about three miles to the southward of Natua, which probably represents a vent of more recent times. Often, however, they have a pseudo-vesicular appearance, from the occurrence in the midst of the patches of interstitial glass of minute irregular cavities that seem to have been formed during the last stage of consolidation of the magma.

The prevailing type of basalts is a blackish, doleritic, semi-ophitic rock without olivine, with specific gravity 2.78 to 2.80. They are characterised by the length of the feldspars of the ground-mass (.22—.35 mm.), by the large size of the augite granules (.1—.3 mm.), and by the quantity of dark interstitial glass. They present two forms, one with and the other without plagioclase phenocrysts. The first kind is referred to genus 9 of the augite-andesites (page 272), some of the specimens being referred to the porphyritic sub-genus, and others to the non-porphyritic sub-genus, according to the size of the plagioclase phenocrysts. The

second kind, without felspar phenocrysts, belongs to genus 12 of the same class (page 275). A good example of the porphyritic rocks is afforded in the large blocks lying in the stream-beds during the first half of the way from Ndreketi to Sarawanga.

It may be pointed out here that these doleritic, semi-ophitic basaltic andesites of the Ndreketi plains differ conspicuously from the prevailing type found on the slopes of Seatura, on the Sarawanga and Mbua plains, and on the Wainunu table-land. There we have, as a rule, olivine-basalts, having a specific gravity of 2·86 to 2·90, and showing but scanty interstitial glass, the felspars of the groundmass being on the average not over 2 mm. in length, whilst the augite granules are, as a rule, only 0·02—0·03 mm. in diameter, and the ophitic structure is infrequent.

The submarine deposits, consisting of foraminiferous clays and coarser tuff-sandstones, the former being usually beneath, are found at intervals all over this area. They occur inland as far as Vuinasanga and Nareilangi, near the base of the mountains of Va Lili and Na Raro, reaching as high as 300 feet, their place being taken on the mountain slopes by coarser tuffs and agglomerates. When not weathered they are more or less calcareous, and contain occasionally marine molluscan shells, whilst palagonitic debris enter largely into their composition. The foraminiferous clays, often much bleached by hydration, are well represented around Mbatiri and in the districts between that town and Natua and Nareilangi. They are relatively deep-water deposits, and belong to the type described on page 323. Others, again, as exposed in the banks of the river at Natua, are chocolate coloured and of the kind referred to in detail on page 335. These foraminiferous clays in the region between Natua and Mbatiri are overlain in places by coarse, almost brecciated, tuffs, formed in part of the debris of acid andesites, such as compose the not far distant mountain of Na Raro.

Since the massive basaltic rocks are exposed in all the deeper rock channels of these plains, it is apparent that the overlying submarine deposits can possess no great thickness. Probably they are never 100 feet thick, and usually far less. In many places, through their denudation, the underlying basaltic rocks are exposed, and in a decomposing condition largely form the surface. These deposits as a rule display bedding, the beds being horizontal or at least only inclined 2 or 3 degrees. This horizontality is a nearly constant feature of these submarine beds, as they overlie the basaltic rocks of the plains; and it is a feature we should

expect to find where there has been emergence rather than upheaval.

Siliceous concretions and silicified coral fragments, so characteristic of the surface of some of these plains of Vanua Levu, did not frequently come under my notice here. They, however, occur occasionally, as in the district between Nanduri and Natua.

THE NAWAVI RANGE.

With this remarkable coast range, which fronts the Mathuata sea-border for a distance of 12 or 13 miles between Ravi-ravi Point and Nanduri, I have unfortunately but scant acquaintance. It attains its maximum elevation in Mount Nawavi of 2,238 feet, and is described by Mr. J. P. Thomson,¹ who surveyed this coast, as broken in two nearly opposite Niurua, the pyramidal mountain of Koro Navuta rising in the gap. Various other peaks, besides that of Nawavi, are marked in the latest Admiralty chart; they vary in height from 1,000 to 1,700 feet. As this range lies only a mile or less back from the beach, it gives to the sea-border a bold and often precipitous appearance, which is well shown in an illustration in Wilkes' *Narrative of the United States Exploring Expedition* (iii. 226).

Basic rocks probably prevail in this range. When I ascended its eastern spurs from Nanduri, and reached a height of 800 feet, only basic tuffs and agglomerates came under my notice. From Dana's remarks² it is to be inferred that the "frowning bluffs" opposite Mathuata Island are of similar formation; and it would seem that the rugged black stones, described in the *Admiralty Sailing Directions*³ as topping the hills behind Ravi-ravi Point, are of the same basic character. From its contour and profile I would gather that, as in the great mountainous ridges that constitute the backbone of the island between Va Lili and Mount Thurston, palagonitic tuffs and clays of submarine origin will, together with volcanic agglomerates, be found far up the slopes of this range, and that the axis will prove to be largely composed of massive basic rocks.

The hot springs referred to by Thomson and others as occurring at the foot of the north and south slopes, namely at

¹ *Proceedings*, Queensland Branch, Geographical Society of Australasia, Brisbane, 1886, vol. i.

² *Geology of the United States Exploring Expedition*.

³ *Pacific Islands*, vol. ii. 1900.

Vatuloaloa, Nambuonu, and in another unnamed inland locality, are briefly mentioned on page 31.

THE SEALEVU DIVIDE.—This broad range which separates the Ndreketi and Lambasa basins is an offshoot from the central mountains at Sealevu and reaches the coast just east of Nanduri. Its highest part according to the elevation given in the Admiralty chart is 1,437 feet. The road from Sealevu to Nanduri, which crosses its broad level summit for a distance of about three miles, does not rise over 1,100 feet. Between 800 and 1,100 feet are exposed calcareous tuffs and clays all largely made up of palagonitic materials. The coarser might be described as sandstones. The clays have 12 per cent. of lime and are foraminiferous and are of the type described on page 321. The rocks displayed on the lower northern slopes on the way to Nanduri are at first the same submarine deposits, and afterwards decomposing basaltic andesites. It is apparent that in the central elevated part of this range there are hills of volcanic formation more or less completely buried beneath these deposits.

THE DISTRICT BETWEEN NANDURI BAY AND WAILEVU RIVER

The sea-border between Nanduri Bay and Middle Point, nearly four miles to the east, consists of a fringe of lowland margined by the mangrove-belts and banked by a line of hills between a quarter and two-thirds of a mile inland. These hills form a continuation of the Nawavi coast range of mountains extending from Raviravi Point to Nanduri. They attain their greatest height in the case of Ulu-i-sori, a cockscomb-like peak 1,141 feet above the sea. Another of these hills, Vatu-tangiri, is capped by a remarkable obelisk-like rock. Behind this coast range lies a hill with an elevation of nearly 1,400 feet.

The rocks exposed for the first mile or two along the coast east of Nanduri are agglomerates and basic tuffs. The blocks of the agglomerates, however, are made of an altered grey porphyritic rock which has the characters of a porphyrite of a rather acid type.¹ This composition of the agglomerate is quite exceptional

¹ It is referred to the 5th sub-order (genus 18) of the hypersthene-augite-andesites characterised by prismatic pyroxene and more or less parallel felspar lathes in the groundmass, as described on p. 289. It displays abundant opaque porphyritic plagioclase giving extinctions of oligoclase-andesine. The pyroxene phenocrysts have dark alteration-borders. There is a little altered interstitial glass. Spec. grav. 2.55.

and indicates the antiquity of the volcanic rocks in this locality. Farther along the coast the typical agglomerates occur, where the blocks, 3 to 10 inches across, are composed of the usual semi-vitreous black basaltic rock showing plagioclase phenocrysts. Nearer Middle Point a decaying doleritic basalt is displayed at the surface. It is similar to the prevailing rock of the Ndreketi plains, and is referred to the ophitic rocks forming genus 9 of the augite-andesites.

The elevated promontory of Middle Point is a prolongation of a spur of Ulu-i-sori. Where it is crossed by the road it is about 350 feet above the sea. On its west slopes are exposed yellowish-white tuff-like rocks, evidently the prevailing basic clay-tuffs which have become bleached through the hydration accompanying the weathering process. Beneath these deposits lies an amygdaloidal augite-andesite which is bared in places. The rock is semi-vitreous and the amygdules it contains are often a centimetre long. They are composed of a white mineral with fibro-radiate structure and made up of needle-like prisms. It gives off water, but it is not easily fused, and does not gelatinise in HCl.

From the top of the promontory the road strikes inland in an east-south-east direction for Tambia, passing inside the coast range, which is here 600 feet in height, and descending gradually through a region of basaltic andesite into the valley of the Tambia river. (This rock, which has a specific gravity of 2.84, displays more or less parallel stout felspar-lathes, .23 mm. in length, and has a little interstitial glass. It belongs to genus 13 of the augite-andesites.) Low hills shut in the little valley on all sides except where the river breaks through the coast range. The town of Tambia is not over 100 feet above the sea. About a mile to the north exist hot springs of considerable extent which are described on page 32.

The road from Tambia to the Wailevu River traverses an undulating district varying from 100 to 300 feet above the sea. A basalt containing a little olivine, with a specific gravity of 2.91, is commonly exposed at the surface in a disintegrating condition. Here and there occur basic tuffs. In one locality, there is displayed a dyke-like mass in a small stream course, 200 feet above the sea, of an altered grey and compact andesite marked with parallel red streaks or bands. It is an aphanitic augite-andesite; and is to be referred to genus 13 of the augite sub-class. It displays closely crowded felspar-lathes, .07 mm. in length, in flow-arrangement. The bands are due to the gathering of the residual glass in streaks

parallel to the flow. Chalcedonic flints, some of them showing the agate-structure, together with fragments of silicified corals, are found occasionally on the surface in this district.

THE LAMBASA PLAINS

These remarkable inland plains, about ten miles long and three to five miles broad, are well described in the Admiralty chart as a low undulating country covered with grass, screw-pines, and Casuarina trees. They are backed by the mountains forming the central axis of the island, whilst broken groups of hills, not usually more than 500 or 600 feet in height and attaining in Ulu-i-Mbau an elevation of 1,160 feet, intervene between them and the sea-border. They are traversed by the Wailevu, Lambasa, and Ngawa rivers which after breaking through the seaward hill-ranges pass through broad mangrove-belts to reach the coast. The tide ascends these river-courses for several miles; and in the case of the Lambasa river boats can follow its winding course for ten miles penetrating into the heart of the plains. Much of this level inland region is less than 100 feet above the sea; whilst the contour line of 300 feet by which the region is defined in the map attached to this book fairly well indicates the higher levels.

The features which we have described in the instances of the Sarawanga and Ndreketi plains are in the main reproduced in the Lambasa region; but in the last-named each of the three rivers has a system of hot springs along its course, namely (as described in Chapter III.), at Na Kama on the Wailevu River, at Vuni-moli on the Lambasa River, and at Mbatini-kama on the Ngawa River. Basaltic andesites, often exposed at the surface in a decomposing condition, form the foundation of the plains. They are overlain by submarine clays containing pteropod shells and tests of foraminifera; and over these in their turn coarse palagonitic tuffs and agglomerate-tuffs are found in places. Formations still more recent are represented by elevated reef-rock on the seaward side of the hills that bound the plains. Nodules of chalcedony, silicified corals, and other siliceous rocks, together with fragments of impure limonite, lie on the surface over much of this region.

The basaltic rocks of this region rarely show olivine, and belong as a rule to the basaltic andesites, being referred to genera 13 and 21 of the augite-andesites, the specific gravity being about 2.8. The felspar-lathes, .12 to .14 mm. in length, are in flow-arrangement, and the augite is at times semi-ophitic; whilst there is a little

interstitial glass. The basic rocks prevailing between Vatu-levoni and Vandrani belong to genus 13 of the augite-hypersthene-andesites and have a groundmass of much finer texture, the feldspars only measuring .05 mm. Their specific gravity ranges between 2.7 and 2.75.

The overlying foraminiferous and pteropod clay rocks, the so-called "soapstone," are exposed over large areas of the surface. A good idea of the important part they take in the formation of the lower plains may be formed by visiting the hot springs of Vuni-mbele, close to Vuni-moli, which issue from the side of a deep trench cut into these deposits. As generally displayed at the surface, they have been subjected to so much hydration in the weathering process that they appear as yellowish-white clay-rocks deprived of their lime; and it is only now and then that the remains of foraminifera and pteropods can be detected. They are, however, fairly well preserved around the base of Ulu-i-mbau in the vicinity of Koro-wiri, where they contain, besides the shells of pteropods and foraminifera, portions of decaying coral, and extend to 200 feet and over above the sea. Here they are overlain by rather coarser basic tuffs of mixed character, containing 5 or 6 per cent. of carbonate of lime and some palagonite, which I followed as high as the track lay, rather over 500 feet above the sea.¹ The reef-limestones, already noticed as exposed in the low hills between Wailevu and Lambasa, lie a mile or two inland and reach to 100 feet above the sea.

The fragments of siliceous rocks, which with occasional bits of impure limonite, occur at intervals all over the surface of these plains and largely form the gravel and pebbles in the river-beds, include nodules of chalcedony, fragments of jasper or iron-flint, white quartz-rock formed of chalcedonic silica, silicified corals, &c. They are especially frequent in the vicinity of Nasawana and Koro-utari, and include fine specimens of agates and of onyx.

¹ I did not ascend to the top of Ulu-i-mbau. It is, however, evidently composed of basic andesitic rocks, occasionally amygdaloidal. On its slopes up to at least 600 feet above the sea occur agglomerate-tuffs and finer submarine tuffs, as above described, overlying foraminiferous clays, a submergence of quite 500 feet being indicated by the investing deposits.

CHAPTER X

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE VA-LILI RANGE

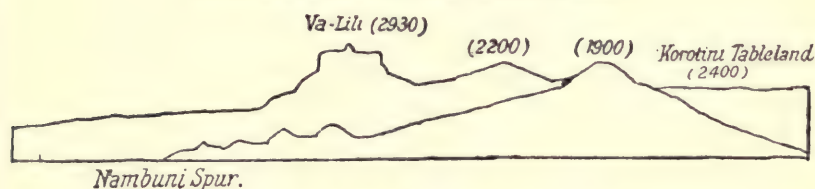
THIS range extends from the Na Raro Gap before mentioned to the Ndreke-ni-wai river. It is partly isolated on the north-east from the Korotini Range, the extension eastward of the mountainous axis of the island, by a depression or saddle which at its lowest part is not more than 1,200 or 1,300 feet above the sea; but there is no real break in the line of mountains. It is, however, convenient to make this distinction, and I have named the dip between the two ranges, the Waisali Saddle. The range now to be described attains its greatest elevation in the summit of Va-lili, which is 2,930 feet above the sea. There are two or three other peaks that exceed 2,000 feet, and much of the range is not under 1,700 feet. My acquaintance with this range is not extensive; but it will serve to illustrate its general geological structure.

The summit of Va-lili is very conspicuous from most points of view. From the north, east, and south-east, it has a remarkable broad and square-topped profile with a little conical elevation in the centre. From the south-west, it displays a different outline with a solitary squarish block on the top, and this is the form most familiar to the navigator. Unfortunately, for reasons given below, I did not quite reach the summit, and although I was able to obtain sufficient data for forming a general idea of the structure of this part of the range, the structure of the actual summit has yet to be ascertained.

(1) ASCENT OF VA-LILI FROM NARENGALI.—This village, which is elevated 400 feet above the sea, lies about two miles in a direct line, N.N.E. from the peak. In traversing the intervening

country, one crosses the Loma-loma ridge, elevated 1,000 feet, on the top of which was once situated the village of Loma-loma visited by Horne in 1878. The rocks exposed on the surface are scanty, a hard palagonite-tuff, which owes its induration to a calcitic cement, occurring on the upper part of the ridge, the original site of the village being marked by a large block of this stone.¹ The track then descends into the valley of the Loma-loma river, about 400 feet above the sea, in the bed of which occur blocks of an amygdaloidal basaltic andesite, containing phenocrysts of both rhombic and monoclinic pyroxene, and referred to genus 1

PROFILE-SKETCHES OF THE VA-LILI RANGE.



View from the south-east near Savarekareka.



View from the south-west.

of the rhombic pyroxene andesites. The amygdules are formed of calcite.

Beyond the river the ascent of the northern slope of Va-lili begins. As high as 1,100 feet occur basic agglomerates overlying fine and coarse palagonite-tuffs, which are at times horizontally bedded, the finer kinds being sometimes calcareous, and like that of the Loma-loma ridge above mentioned. At 1,300 feet is a line of tall cliffs which extend for some distance at intervals along the mountain-slope, and are indicated by some fine waterfalls. My track struck these cliffs at a place named "Nangara-ravi" (the leaning cave-rock) where they have a height of 150 feet or more. The tall cliff leans slightly forward, so that it forms a shelter at its foot, and hence the name. It is composed of a tuff-agglomerate,

¹ I did not find any foraminiferal shells or other organic remains either in this tuff or in the similar tuffs occurring on the adjacent slope of Va-lili up to 1,100 feet. My specimens, however, are very small.

the blocks, which are formed of a semi-vitreous basaltic andesite of the augite class, being not generally more than 3 or 4 inches across. These blocks, which are rounded on the outer exposed side and angular on the imbedded side, are inclosed in a hard, probably calcareous matrix. The whole face of the cliff has the appearance of having been worn smooth by attrition, and there are not to be observed the projecting blocks from its surface which are so characteristic of other agglomerate-cliffs. It shows no stratification; but at its base flush with the cliff-face are large masses of a basic massive rock. But few portions of rock have been detached from the cliff. However, I found in the midst of a huge fallen fragment of the agglomerate a dyke-like mass of a basaltic andesite, which differs chiefly from the rock forming the blocks of the agglomerate in being more crystalline. This dyke must have been about 15 feet thick.

Having regard to these various features, I am inclined to consider that this leaning cliff represents one side of a large fissure in the agglomerates which was occupied by a dyke. Reference has been above made to the fact that the agglomerates may be seen overlying the tuffs farther down the slope, so that the conditions favourable for landslips exist. I have shown on page 111 that the origin of the Mbenutha cliffs where agglomerates lie on clayey tuffs may be thus attributed to a landslide. In the case of the Nangara-ravi cliffs, the occurrence of this fragment of a large basaltic dyke is of some importance in connection with the origin of the basic agglomerates of this locality.

The top of the mountain-ridge is about 700 feet above Nangara ravi, or 2,000 feet above the sea. The tuffs and agglomerates that once existed here have been stripped off to a great extent and the deeper rocks of the range are in part exposed. The upper part of this ridge (1,700 to 2,000 feet) is formed of a rubbly pitchstone where a basic glass has been broken up and then consolidated, the interstices being filled up with palagonite as described in other cases on page 313. Though non-vesicular, it is just such a rock as one would expect to find on the surface of a lava-flow or on the sides of a dyke.

The crest of the range is here only a narrow ridge. I followed it along in a north-west direction, gradually ascending on the way, and in time the rubbly pitchstone gave place to a hardened palagonitic clay rock, which was observed as high as 2,300 feet. It apparently contains a little lime, and probably was at one time foraminiferous; but it is now much affected by hydration. Soon

after this, we arrived at the foot of the steep ascent leading to the summit of Va-lili. We were now rather over 2,400 feet above the sea; but my natives refused to go on, the heavy rain having made the slope too slippery for a safe ascent. With much reluctance I retraced my steps; and as the bad weather continued for several days after, I did not make another attempt. There would, however, be no difficulty in dry weather.

(2) TRAVERSE OF THE VA-LILI RANGE FROM THE OLD SITE OF LOMA-LOMA TO WAIWAI ON THE COAST OF SAVU-SAVU BAY.—This route, which was taken by Mr. Horne, the botanist, in the reverse direction in 1878, is thus described in his book, *A Year in Fiji* (p. 19): "The path, rough and apparently not much used, ran along streams, up steep ascents and down awkward descents, over slippery boulders and fallen trees, up the sides and along the crests of densely wooded mountains."

Ascending the north slope of the range I found at the Tangi-nandreli cave, which is 1,050 feet above the sea, a palagonite-tuff-sandstone underlying the basic agglomerate. This tuff, which is of the type described just below, does not effervesce with an acid, and shows no tests of foraminifera when examined with a lens. Further up the slopes large masses of agglomerate occur. At 1,350 feet I came upon a large mass of a fine-grained compacted palagonite-tuff made up chiefly of fragments of palagonitized vacuolar basic glass. Among the mineral fragments occur plagioclase, augite, and rhombic pyroxene, and a little fresh olivine, which is of very rare occurrence in these palagonite-tuffs. It contains little or no lime, and shows no tests of foraminifera in the slide. The summit of the range is here about half a mile broad, and is relatively level. I placed its elevation at 1,760 feet, which is not far from Horne's estimate of 1,800 feet. The southern slope, which is the rainy side of the range, is much cut up into gorges. In the upper 200 feet palagonite-tuffs, similar to those above referred to, are displayed, and basic agglomerates occur lower down. This part of the range is remarkable through being completely covered over by palagonite-tuffs and agglomerates. It has been pointed out above that this is not the case with the range close to the highest peak, where the underlying rocks are in part exposed at the crest of the range.

(3) THE EASTERN PEAK OF THE VA-LILI RANGE.—This hill, about 1,100 feet in height, overlooks the Mbale-mbale branch of the Ndreke-ni-wai river. At its foot near the river there is exposed at the roadside a rubbly pitchstone formed of a basic glass,

inclosing porphyritic crystals of plagioclase, augite, and olivine, which is described on page 313. Here also occurs an agglomerate made up of blocks of a semi-vitreous basaltic andesite (sp. gr. 2·78), showing prismatic pyroxene in the groundmass, and referred to genus 20 of the augite-andesites.

The upper part of the hill displays the same agglomerate, and a tuff-agglomerate in which small fragments of the basaltic andesite are inclosed in a matrix largely made up of fine debris of basic glass. There protrudes through these detrital rocks at the top of the hill a broad dyke-like mass of the same basaltic andesite that forms the agglomerate around; and the structure of the hill is thus displayed as that of an old volcanic neck. It has evidently an axis of massive basaltic rocks, more or less covered over with agglomerates and tuffs.

(4) THE NAMBUNI SPUR.—This singular spur runs down to the coast between Waiwai and Wailevu; but it is partly separated by a deep gap from the main range. It attains a height of 550 to 600 feet, and has two little peaks which the natives call Vatu-tolutolu and Vatu-tangitangiri. Its position is shown in one of the profile-sketches of Va-lili, given on page 141. The crest of the spur is formed by a dyke-like mass, 25 to 30 feet thick, which is composed of a basic agglomerate passing down into a palagonite-tuff. The blocks of the agglomerate are composed of a semi-vitreous basaltic andesite, showing minute felspar-lathes in flow-arrangement in an abundant smoky glass, the fine pyroxene being not differentiated. The tuff, into which the agglomerate passes down is non-calcareous, and displays no organic remains. It is, however, composed of fragments, which do not generally exceed a millimetre in size, of palagonitised vacuolar glass, basic andesites, plagioclase, monoclinic and rhombic pyroxene, &c.

This dyke-like mass forms the axis of the ridge and protrudes vertically about 100 feet, the bulk of the spur being composed of a compacted brecciated palagonite-tuff made up mainly of fragments a centimetre in size, of a basic vacuolar glass, sometimes fibrillar, which is extensively palagonitised.

The filling up of a fissure in a mass of tuff-breccia by palagonite-tuffs and agglomerates probably occurred during the submergence, the original dyke-rock having been removed by marine erosion. After the emergence the subaerial denuding agencies reshaped the surface, and as a result of the less yielding character of the materials filling the fissure, they protrude as a dyke-like mass from the crest.

In a cliff-face of the adjacent main range there are displayed an agglomerate of basaltic andesite and a pitchstone-breccia, composed of fragments of but little altered basic glass, the interstices being filled up with palagonite. In the case of the Kiombo flow I have endeavoured to explain the origin of a closely similar pitchstone-breccia (page 92).

(5) THE SEA-BORDER AND THE LOW-LYING DISTRICTS AT THE BASE OF THE VA-LILI RANGE.—It may be generally remarked that palagonite-tuffs and clays, often foraminiferous, prevail in these localities. Thus in the sea-border between Waiwai and the mouth of the Ndreke-ni-wai basic agglomerates are displayed where the mountains approach the coast; but further west a broad tract of undulating land, elevated usually 100 to 300 feet, intervenes between the range and the sea-border, and here coarse and fine palagonite-tuffs predominate. On the north-west the foraminiferous tuffs and clays of the Ndreketi plains approach the Va-lili range in the vicinity of Vuinasanga, and extend for at least 200 or 300 feet up its sides. At the east end of the range, where the slopes descend to the plains of the Waisali valley, a little west of Mbale-mbale, there are exposed bedded palagonite-tuffs, tilted up at an angle of about 20° to the south-west. They contain a little lime and display microscopic tests of foraminifera, the palagonite being minutely vacuolar, the cavities also being filled with the altered glass. I noticed those submarine deposits at an elevation of 100 feet, but probably they reach much higher.

The inference to be drawn from the data above given concerning the Va-lili range seems clearly to be this. We have here indicated the emergence of a submarine mountain-ridge covered over with palagonite-tuffs and agglomerates, the last being uppermost. These coverings have been in places stripped off by the denuding agencies and the underlying massive basic rocks exposed. These rocks, however, vary much in texture, some being vitreous, as in the case of the pitchstones, others hemi-crystalline as in the case of the basaltic andesites; and it is to be gathered from this and other similar indications that different submarine vents were formed along a fissure or fissures at the sea-bottom. No evidence of sub-aerial eruptions came under my notice. After the vents became extinct they were buried beneath the palagonite-tuffs and agglomerates. During and after the emergence the denuding agencies reshaped the surface of the range and left but little of its original form.

Since it is my object to build up a theory of the origin of the

ridge-mountains as I proceed with the systematic description of the island, it will be here convenient to follow up the preceding remarks on the Va-lili Range by a preliminary reference to the great ridge district lying east of it.

When a panoramic view of this region is obtained, one observes a series of lofty ridges more or less parallel and running about N.W. and S.E. There are the Va-lili, Narengali, and Sealevu ridge-mountains with lesser ridges between. The intervening valleys are elevated about 400 feet above the sea, whilst the mountains rise up to over 2,000 feet. In many localities this configuration of the surface would be attributed mainly to subaerial denudation. In this island I will endeavour to show that these mountain-ridges existed before the emergence. They do not owe their form to the rivers that flow through the valleys, though no doubt river-erosion has brought these features into greater relief.

In Vanua Levu, as there will be frequent occasion of showing, rivers often flow in valleys that they have not made. This is especially pointed out on page 151; and it is necessary to emphasise it here, before proceeding farther with the description of the geological structure of the mountain-ridges.

THE WAISALI SADDLE

This saddle, which connects the Va-lili and the Koro-tini ranges, has probably a minimum elevation of not over 1,200 or 1,300 feet. To understand this district thoroughly a regular survey is, however, necessary. It is only at times in this densely wooded range that a view of the surrounding country is obtained; but in spite of this drawback I was able by a diligent use of watch, aneroid, and prismatic compass, to obtain a fair general notion of the surface-configuration.

The track that proceeds westward from Waisali to Narengali leads also to the villages of Na Sinu and Sealevu. About $1\frac{1}{2}$ or 2 miles from Waisali, the track branches off to the westward for Narengali and to the northward for Na Sinu and Sealevu. After half an hour's walk along this last-named path, one comes to a place where at an elevation of about 900 feet it branches off to the left for Na Sinu, crossing the lowest part of the saddle, and to the right for Sealevu across the Koro-tini Range. It may here be remarked that since the natives are gradually abandoning their mountain-villages and are settling at the coast, many of the mountain-tracks used by me will before long be overgrown and forgotten.

In taking the path from Waisali to Narengali one soon enters the hilly country where large masses of basic tuffs and basic agglomerates, the last formed of blocks of a compact basaltic andesite, occur on the surface up to 700 or 750 feet above the sea. The rock just named has a specific gravity of 2·84, and since it displays rhombic pyroxene amongst its phenocrysts, it is placed in genus 1 of the hypersthene-augite andesites. Above this elevation, and as far as the top of the range, 1,800—1,900 feet above the sea, porphyritic basaltic andesites, having a specific gravity of 2·8, prevail at the surface. They display small porphyritic crystals of plagioclase, augite, and rhombic pyroxene in a groundmass composed of small felspar-lathes, prismatic pyroxene, and much smoky glass, and are referred to genus 5 of the same pyroxene andesites. It is probable, judging from one of these exposures, that such rocks are dyke-like masses: but on account of the thick soil-cap it is not possible to obtain a good view of them.

In the stream-courses occur large blocks of altered basaltic andesites of the propylitic type, having a specific gravity of 2·64 to 2·70, and exhibiting abundant alteration products, such as calcite, viridite, &c. These propylites, I presume, constitute the deeper portion of the range. It will often be necessary to distinguish between the altered basaltic andesites, such as are above referred to, and the relatively fresh rocks of the same type. The former are light coloured (sp. gr. 2·6 to 2·75), and are only exposed in gorges and stream-courses that deeply score the mountain-slopes. The latter are blackish (sp. gr. about 2·8), and at times penetrate the covering of tuffs and agglomerates.

Descending the opposite or north-west side of the saddle-range, one finds the same basic andesites, both fresh and altered, down to about 1,100 feet above the sea. Then the track leads one down a precipitous slope into the picturesque gorge traversed by the headwaters of the Narengali River. At its lower end the gorge opens out into the broad Narengali valley, and here the dense forest of the higher districts gives place to the scanty vegetation of the "talasinga" region.

The rocks exposed in the sides of the gorge are basic agglomerates overlying palagonitic tuffs of mixed composition and evidently sedimentary. On the bottom lie huge masses, some of them 70 or 80 tons in weight, of altered grey aphanitic or non-porphyritic augite-andesites, penetrated in some cases by thin veins of white quartz, and at times displaying a rudely columnar structure, the columns being 12 to 14 inches across. Sometimes the alteration is

mainly confined to the filling of the fissures with chalcedonic quartz, minute nests of the same material occurring in the groundmass. At other times the small augite granules are also decomposing. The specific gravity varies from 2.64 to 2.73; the rocks being referred to genus 16, species A, of the augite-andesites. Occasional detached masses of a propylitic basic andesite, displaying porphyritic plagioclase and pyroxene, also occur in this gorge, the felspar phenocrysts being largely occupied by calcitic and other alteration products, whilst much viridite occurs in the groundmass. It exhibits both monoclinic and rhombic pyroxene; and on account of the prism form of the groundmass pyroxene it is placed in the 2nd sub-order of the hypersthene-augite andesites. These altered rocks are deep-seated intrusive masses that were originally covered over by the basic agglomerates and palagonite-tuffs exposed in the sides of the gorge.

Below the gorge there is an extensive exposure in the sides and bed of the river of light-coloured calcareous tuffs which were originally composed of palagonitic materials; but owing partly to hydration, and partly to other secondary changes, the original structure is much disguised.

Crossing the river in the midst of these tuffs there is a dyke, 15 feet thick, formed of a propylitic basaltic andesite, a semi-vitreous rock in which calcitic and zeolitic materials have been developed in quantity. The dyke, which is not columnar, is steeply inclined at an angle of 45° to the north-east. . . . Further down the river-valley as far as Narengali, occur basic tuff-agglomerates.

THE TRACT OF NAKAMBUTA

This is a tract of broken country that projects from the mountainous backbone of the island (between the Va-lili and Korotini ranges) into the heart of the Ndreketi plains in the vicinity of Natua. As limited by the 300-foot contour line, it is indicated in the map attached to this work. Its general level varies between 300 and 600 feet in elevation; but a number of isolated peaks are included within this area. More than one of these hills attain a height of 1,000 feet, Nakambuta a very conspicuous hill being as much as 1,500 feet. Basaltic andesites with basic agglomerates and palagonite-tuffs prevail.

Towards Natua the basaltic andesites, which are often much decomposed, are of the doleritic type referred to in the account of the Ndreketi Plains on page 133. Inland, towards Narengali and

Va-lili, these rocks are often more or less glassy and take the form of pitchstones; whilst the agglomerates have the same character. The first probably represent submarine flows of basaltic lava which have spread far and wide over the Ndreketi plains. The inland rocks are, as is pointed out below, the products of vents that, as in the case no doubt of Mount Nakambuta, rose out of a shallow sea. The palagonite-tuffs and clays, often foraminiferous, which cover the Ndreketi plains, are extensively represented in the lower levels up to 400 feet or more.

Between one and two miles to the westward of the Narengali valley, and immediately north of Va-lili, the agglomerates, overlying palagonite-tuffs, form lofty precipices. The agglomerates are composed of blocks of more or less vitreous basaltic-andesites, some of them semi-vitreous and amygdaloidal, some in the form of pitchstone, and others again as tachylyte that fuses in the lamp-flame. The underlying palagonite-tuffs are bedded, and are composed of fragments of basic glass that originally inclosed porphyritic crystals of plagioclase. In the slide it is observed that the glass and mineral fragments have often been re-fractured as they lie in the tuff and that the former have rounded angles and eroded edges. The interstices are filled with a more or less palagonitised magma. Similar rocks occur in other localities, and they will all be found described on page 334. It may, however, be remarked here that in all cases these rocks would seem to have undergone some crushing, the heat developed in the process being sufficient to partially remelt the glass. A high temperature was not required to effect this fusion, since splinters of the tachylyte occurring in the overlying agglomerate fuse in an ordinary lamp-flame. It is pointed out on page 341 that tuffs of this character differ in origin and in characters from the prevailing foraminiferous palagonite-tuffs.

The road from Narengali to Natua traverses the length of this district. At and near the mouth of the Narengali valley there are exposed basic tuffs and agglomerates, the blocks in the last case being formed of a semi-vitreous, vesicular or almost scoriaceous basaltic andesite. In this neighbourhood the track passes across the top of a waterfall which is the result of the existence of a huge dyke-like mass of a compact basaltic andesite showing a little interstitial glass and referred to genus 13 of the augite-andesites. It lies in a district of tuffs and agglomerates. Farther on, about two miles north-west of Narengali, the track crosses some rounded hills, elevated about 600 feet, on the top of which is displayed a

concretionary pitchstone, showing little nodular concretions of the size of filberts, and having the microscopical characters of "variolite," as described on page 313. This is the only locality of this rock that is known to me.

My acquaintance with the tract of Nakambuta is, however, very imperfect. But it is apparent that in the pitchstones and in the semi-vitreous basic rocks, sometimes vesicular and amygdaloidal, we get a nearer approach to the products of subaerial eruptions than is to be observed in most other portions of the island. The examination of the Nakambuta peak by some future investigator will bring to light some interesting facts concerning this region. It is not unlikely that during a late stage of the emergence of this region Nakambuta and the other peaks around protruded as active vents above the surface of a shallow sea, at the bottom of which the products of their eruptions accumulated.

THE VALLEY OF THE NDREKE-NI-WAI AND ITS TRIBUTARIES

Ndreke-ni-wai, which signifies "the hollow of the water," is the name of a broad tidal estuary, opening into Savu-savu Bay, which is formed by the union, about half a mile above its mouth, of two rivers, the Mbale-mbale River flowing from the north-west past a village of that name, and the Vatu-kawa River, the largest, flowing from the eastward, which I have also named after a village on its banks. The valleys of these two rivers are separated by a mountainous dividing-ridge connected by a saddle with the main range. Its highest peaks rise to 2,100 feet above the sea, the elevation of this "divide" rapidly decreasing as it approaches the coast, where, within a mile of the beach, it terminates in some low hills 200 or 300 feet in height.

It may be observed here that a mouth of the river was originally situated 700 or 800 yards to the west of its present site. This old mouth is now represented by a lagoon communicating with the Mbale-mbale River above, but closed by the sand-mound of the beach at its lower end, which, however, is occasionally broken through when the rivers are in flood. This lagoon is shown in the view facing page 153.

The valley of the Mbale-mbale River, which is much the smaller of the two rivers, is bounded on the north by the precipitous slopes of the Koro-tini Range, which rise to over 2,000 feet, and on the south and west by the lofty Va-lili Range. The

valley, above the village of Mbale-mbale, is broad and low-lying ; and one can ascend it to the vicinity of Waisali, three to four miles from the river's mouth, without attaining an elevation of 100 feet above the sea. The main stream, which flows down from Waisali, is joined near Mbale-mbale by a more impetuous stream that descends the steep mountain-sides just to the east of the Koro-tini Bluff.

The valley of the Vatu-kawa River is bounded by lofty mountain-ranges that rise to elevations varying from 2,000 to 3,500 feet. On the south side lies the Mariko Range, on the east lies Mount Mbatini, the most elevated peak of the island, whilst on the north rise up the steep slopes of the Koro-tini Range and of the mountainous "divide." The valley has such a gentle gradient that one can follow it inland for five or six miles from the estuary to the vicinity of Nukumbolo without exceeding an elevation of 100 feet above the sea. Below Na Salia the valley is confined between the hills that approach the river ; but above that village it is very broad ; and on account of its slight fall the river here often changes its course, so that the floor of the valley is strewn with water-worn blocks and pebbles marking the old channels.

The Vatu-kawa River, which rises on the west slopes of Mbatini, flows with a placid current past Nukumbolo and Na Salia, until it reaches the village of Vatu-kawa, where it is joined by its impetuous tributary, the Wai-ni-ngio, "the river of the shark." This affluent, after descending the steep slopes of the Koro-tini mountains, bursts through the dividing range that separates the Mbale-mbale and the Vatu-kawa valleys. It would seem that the Wai-ni-ngio without any great effort on its part might become a tributary of the Mbale-mbale River.

The great character of these two valleys, as shown above, is their little elevation above the sea. For miles inland the level does not attain 100 feet, and high ranges rise steeply in each case on either side to 2,000 feet and over. Here, as in the instance of most of the large valleys of the island, the original configuration of the surface was not dependent on river-erosion. Rivers no doubt have done much to carve out the lesser and to deepen and widen the greater valleys ; but, as is often remarked in this work, the main features of the surface were in existence before the emergence of the island from the sea.

The geological formation of the slopes of these two valleys is described in the accounts of the various ascents of the mountains bounding them. Since foraminiferous tuffs occur high up their

sides, up to elevations of 2,000 feet and over, the valleys themselves were at one time no doubt also covered with these submarine deposits, which, however, have been in great part stripped off by the denuding agencies. They are still to be found, containing large tests of foraminifera, between Mbale-mbale and Waisali; but the basaltic andesites, originally underlying them, are more frequently exposed. One of these rocks found a little east of Waisali, which has an aphanitic appearance and a specific gravity of 2.82, is merely a basic glass in its early stage of crystallisation, being made up of very minute crystallites $\frac{1}{8000}$ of an inch in length. On the surface in this locality there also occur basic agglomerates containing scoriaceous rocks, the products of some of the last stages of volcanic action in this part of the island. . . . In the case of the broad part of the Vatu-kawa valley above Na Salia blocks of basic rocks derived from the mountains around strew the bottom in great abundance. Lower down, where the valley is confined between the hills, basic agglomerates and coarse tuffs are displayed in the hill-sides.

Mention should be made here of the various hot springs existing in these valleys in the low levels near the rivers and stream-courses. In the Vatu-kawa valley they exist at Nukum bolo, and in the Mbale-mbale valley at Natoarau, Waitunutunu and other localities. These springs are described in Chapter III.



DUNIUA LAGOON, representing an old mouth of the Ndreke-ni-wai. Behind rises the Korotini Tableland (2,000—3,000 feet). The cliff-like declivity over the head of the lagoon is the Korotini Bluff.

CHAPTER XI

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE KORO-TINI RANGE OR TABLE-LAND

THE level-topped range that forms the mountainous backbone of the island for a distance of nearly 10 miles is one of the remarkable features of Vanua Levu.¹ In the general profile of the island it is named the Koro-tini Table-land on account of the level profile which it presents whether viewed from the north or from the south. But this is merely its appearance *en masse*. When it is examined in detail it is found that although much of the range has an elevation between 2,000 and 2,400 feet above the sea, it attains an elevation of about 3,000 feet in the case of two gently sloping peaks. With regard also to its table-top, it is necessary to remark that whilst in some portions of the range the summit is broad and level, in others it is much cut up into ridges, and in others again it presents a single narrow crest. Nor can we realise on looking at the profile the extent to which its slopes have been carved out by river-erosion, and we get no indication of the several lofty spurs that descend north and south far into the plains, as in the case of the spur west of Sueni and in that terminating in the Koro-tini Bluff. In the profile the eye ignores the details with which the investigator during many toilsome ascents has filled the pages of his note-books. To this extent it is useful in that it enables him to rise a little above the level of his facts, and permits him (to employ a figure-of-speech) to regard the style and general character of the edifice without being exclusively absorbed in the study of the bricks.

This range, which extends from a mile or two west of Sealevu to a couple of miles east of Sueni, is connected on the west with the Va-lili Range by the Waisali Saddle before described, and on

¹ It rises in the background of the view.

the east with the Thambeyu or Mount Thurston Range by a broken chain of mountains, of which Koro-mbasanga is the most conspicuous. It is connected by an elevated *col* with Mount Mbatini and the Mariko Range to the southward. The name of Koro-tini has been applied to this range because it is familiar to the natives. It signifies "ten towns," and was given to a once populous district on the slopes of the lofty bluff overlooking on the north the mouth of the Ndreke-ni-wai. I crossed the range in four places, namely, between Waisali and Sealevu, between Mbalembale and Vandrani, between Vatu-kawa and Vandrani, and between Nukumbolo and Sueni.

(1) TRAVERSE OF THE KORO-TINI RANGE FROM WAISALI TO SEALEVU.—Starting from Waisali by the Narengali track, I ascended the east slope of the Waisali Saddle, as described on page 146, until an elevation of about 750 feet was reached, when my way lay to the northward across the Koro-tini Range to Sealevu. At 850 feet a singular altered tuff was displayed in position in a stream-course. It shows calcite and pyrites, and is interesting from the fact that although it is made up largely of basic glass the tuff does not seem to have undergone the palagonitic change.

Afterwards, there was a fairly steep ascent to the summit of the range, 2,400 feet above the sea, which has merely a ridge-like crest. Between an elevation of 1,400 feet and the top there are exposed at the surface compacted coarse and fine palagonite-tuffs and agglomerate-tuffs formed of the same materials. They contain often abundant organic remains, such as valves of "Cardium" and "Pecten" shells, macroscopic tests of Foraminifera, and some curious scale-like bodies, showing a concentric structure and about an inch across, which look like fish-scales. It is probable that these interesting rocks extend to a greater elevation than 2,400 feet, which was merely the highest level reached in the traverse, but is not the highest point of the range.

These deposits are made up in mass of a more or less palagonitised basic glass originally containing phenocrysts of plagioclase and pyroxene. The palagonitic process is nearly always far advanced; but it is seen in all its stages, the least altered materials fusing under the blow-pipe into a black glass. The fragments are usually sub-angular in the case of the coarse tuffs; but small rounded pebbles up to half an inch in size and fine water-worn gravel are not infrequent. The matrix is composed of palagonitic debris, portions of crystals of plagioclase and

pyroxene, fine gravel, occasional tests of foraminifera ; and it often contains a fair amount of carbonate of lime, in one specimen tested as much as 13 per cent. The amount of lime, however, varies, being in some places scanty.

The term "conglomerate" could not be applied to the coarser deposits, since the sub-angular and angular fragments always predominate. They could scarcely be deemed "breccias" on account of the mixture with pebbles and gravel. Their character is therefore intermediate between the two. I have used the expression "agglomerate-tuff" because it best describes their appearance. A specimen of such a rock presents a curious mixture, in the well-compacted mass, of angular and sub-rounded fragments of palagonite up to an inch in size, small pebbles and fine gravel of the same material, and detached valves of "Cardium," entire and broken. One is forced to draw the inference that these materials accumulated in shallow water. They are such as might have been produced by the marine erosion of an emerging volcanic island endeavouring to hold its own above the waves. But from the occasional occurrence of blocks of a scoriaceous basaltic rock it would appear that during the formation of the deposits there were periods of eruption.

At times massive and comparatively fresh-looking basaltic rocks are exposed *in situ* on the mountain sides in the midst of these submarine deposits. A specimen obtained at 1,800 feet is a semi-ophitic porphyritic olivine-basalt with a specific gravity of 2.86 and showing a little interstitial glass. The mode of exposure did not admit of my ascertaining the exact relation of these rocks to the deposits. They are no doubt dyke-like masses representing the original fissures of eruption of a submarine vent ; and during the emergence they were covered up with tuffs and deposits, the work of the marine erosion of the emerging land. These, however, are points on which light will be thrown when we come to examine other localities.

Descending the northern slopes of the range from the summit to Sealevu the general course was N.N.E. Several valleys were crossed, of which that occupied by the Na Sinu river was 600 feet in depth, the rivers and streams all flowing to the north-west into the Ndreketi basin. Basic tuffs and agglomerates were exposed at the surface all the way down to Sealevu, 400 feet above the sea.

At the head of the Sealevu valley, about a mile or rather more above the village, and a little east of the track followed in the descent above described, the mountain-range terminates abruptly

in lofty cliffs 400 or 500 feet in height. At their base, which is about 1,000 feet above the sea, once stood the village of Lovutu. These cliffs are formed of basic agglomerate-tuffs which display a horizontal arrangement, but there is no distinct bedding. They have the castellated appearance that often characterises horizontally bedded sedimentary formations. The inclosed rock-fragments vary in size from 18 inches to half an inch and smaller. The larger are angular or sub-angular, and are composed of hemi-crystalline basaltic andesites, scoriaceous and vesicular and sometimes amygdaloidal. The smaller fragments are more or less rounded and of the same material. The matrix is made up of fine detritus of the large fragments and of lapilli of a vacuolar palagonitic basic glass, whilst small crystals of calcite fill the cavities and line the fissures. The phenocrysts of plagioclase and augite inclosed in the altered glass also display extensive alteration, and in the first case are largely replaced by calcite, secondary quartz, and other products. No organic remains came under my notice; but on account of the alteration of the tuff-matrix their preservation could hardly be expected. Bearing in mind, however, the fossiliferous character of the tuffs and agglomerates in the higher part of the range, it can scarcely be doubted that the agglomerate-tuffs of the Sealevu cliffs are also submarine.

Each traverse of the great Koro-tini Range will provide us with new facts to aid us in framing an explanation of the origin of this long mountain-ridge. The principal lesson to be learned from the journey across the range from Waisali to Sealevu, and from the visit to the cliffs, is concerned with the great extent and thickness of these submarine basic tuffs and agglomerates. From 1,000 feet above the sea up to the summit, 2,400 feet in height, they are almost the only rocks exposed, excepting the occasional masses of basaltic rocks, which probably represent dykes. Their maximum thickness must amount to some hundreds of feet.

(2) TRAVERSE OF THE KORO-TINI RANGE FROM MBALE-MBALE TO VANDRANI.—In this traverse the track before ascending to the summit crosses a spur of the Koro-tini Bluff, and then descends into the valley of the Natoarau river on the east side of it. It will therefore be convenient to describe the bluff before giving my description of the journey across the range.

The Koro-tini Bluff is a lofty headland (if I may so term it), lying about four miles inland from the mouth of the Ndreke-ni-wai. It attains an elevation of about 2,000 feet, and terminates above in a line of precipices 300 or 400 feet in height. It represents the

southern edge of the level-topped mountain range behind, and like the Sealevu cliffs on the north side it affords a natural section of its mass. It is shown in the plate facing page 153, where it rises at the back of the lagoon.

Approaching the bluff from Mbale-mbale, one crosses a low-lying district less than 100 feet above the sea before striking the spur. Here and in the lower few hundred feet of the spur are exposed basic agglomerates, and occasionally in the mass a semi-vitreous vesicular olivine-basalt, almost like a pitchstone, and displaying large porphyritic crystals of plagioclase, 5 or 6 millimetres long, the agglomerates being made up of the same material. Higher up, at elevations between 1,000 and 1,500 feet, are exposed coarse palagonite-tuffs made up of fragments, usually 1 to 3 mm. in size, of extensively palagonitised basic vitreous rocks, such as occur in the cliffs above. These tuffs become coarser as one approaches the precipitous bluff, the base of which lies about 1,650 feet above the sea. Here the cliffs present a bare rocky face, some 200 feet high. The lower portion is composed of an agglomerate-tuff, and the upper portion mainly of agglomerates. These deposits display no bedding excepting a single plane of division inclined steeply to the north at an angle of perhaps 40°.

The blocks in the agglomerate-tuff are either angular or sub-angular, and are less than a foot across. They are all composed of more or less vitreous porphyritic olivine-basalts, showing large crystals of plagioclase a fifth of an inch (5 or 6 mm.) in length. But they vary somewhat in character. Some of them, that are vesicular and almost scoriaceous, may be termed from their glassy nature porphyritic pitchstones. Others again, where the groundmass is hemi-crystalline, may be designated porphyritic compact basalts, and are referred to genus 37 of the olivine-basalts.

The matrix of the agglomerate-tuff is made up of angular fragments, up to 5 mm. in size, of singular vitreous and semi-vitreous olivine-basalts, in part palagonitised. There is evidence of crushing *in situ* of some of the porphyritic felspar crystals; but it is not so marked as elsewhere noticed. The palagonite is also in part interstitial, a character that goes to support the view advanced on page 342, that the palagonite may be connected in its origin with the heat developed during crushing, only a moderate temperature being required for the partial fusion of the glass.

In crossing the range by this route from Mbale-mbale one first ascends, as above observed, the spur of the Koro-tini Bluff up to a height of 1,200 feet. The track then descends into the valley-

gorge of the Natoarau river on the east, the bottom of which is 750 feet above the sea, and from here the climb begins. One ascends the bed of the stream course, clambering over slippery rock surfaces up to 1,200 or 1,300 feet, where the stream is left, and the mountain-slopes, often steep and precipitous, are then followed to the summit, 2,000 feet in height. Coarse and fine palagonite-tuffs and agglomerate-tuffs of the same character are exposed on the surface from the commencement of the ascent up to 1,850 feet; but they are displayed much more extensively in the stream-course than in the soil-covered upper slopes.

The tuffs are grey except when hydrated, when they turn yellowish-brown. Some of them contain lime, as much at times as 10 or 12 per cent.; whilst others possess little or none. Tests of foraminifera are not infrequently inclosed, even as high as 1,850 feet. A description of one of these tuffs containing a few tests of Globigerina, which was obtained at 1,200 feet, is given on page 331, under sample D. It will be there seen that they are derived from different basic rocks, some containing but little glass, others mainly vitreous, only the more glassy constituents being palagonitised. The palagonite-tuff sandstones exposed in large blocks on a bare spur at 1,850 feet contain 12 per cent. of lime, the largest tests of foraminifera being not over half a millimetre.¹ These tuffs occasionally show bedding. At 1,000 feet they dip gently to the S.S.W., and at 750 feet they are inclined about 15° in the same direction. In this last locality they consist of alternating layers, 1 to 4 inches in thickness, of fine and coarse tuffs, the coarser looking like sandstone. The blocks in the agglomerate-tuff are sub-angular, and of an olivine-basalt with hemi-crystalline groundmass,² their size ranging from 2 feet to an inch. I noticed one large block of this rock, measuring $2 \times 1\frac{1}{2} \times 1$ feet, imbedded alone in the tuffs at 1,200 feet. At one place a tuff containing small fragments of basalt displayed a concretionary structure, indicating probably the proximity of a dyke, the globular masses being 4 feet across. A little lime occurs in the matrix of the agglomerate-tuff.

The summit of the range, 2,000 feet in height, is "ridgy," about half a mile in width, and cannot therefore be described as table-topped. The rocks exposed in blocks on the surface are composed of a semi-ophitic olivine-basalt containing a large amount of interstitial glass which shows the fibrous crystallites of the early stage devitrification. It is referred to genus 33 of the olivine-basalts.

¹ They are described under sample E on p. 332.

² Referred to genus 37 of the olivine-basalts.

Descending the northern side of the range I followed the steep slopes down to 1,000 feet above the sea. A rubbly doleritic olivine-basalt, semi-ophitic, and assigned to the same genus (33), prevailed on the way; and it is probable that a waterfall with a drop of 50 feet or more that is situated on these slopes indicates a large intrusive mass of this rock. During the rest of the descent to Vandrani, which lies in a valley at the foot of the range, and is elevated about 300 feet above the sea, basic agglomerates and palagonite-tuffs, together with deposits intermediate in character, were exposed at the surface. At times a semi-ophitic doleritic basalt similar to those displayed above, but without olivine, occurred in position. The blocks in the agglomerates are formed of a compact semi-vitreous basaltic rock, and are sometimes vesicular. At one place the palagonite-tuffs exhibited signs of alteration, being traversed by small fissures not over a third of an inch broad (5 to 8 mm.), and filled with a zeolite behaving like natrolite.

In some cliffs by the river at Vandrani are displayed fine and coarse non-calcareous palagonite-tuffs, bedded and dipping about 15° N. by W. They are penetrated by cracks, 5 mm. in breadth, which are filled with chalcedony. These tuffs are evidently in part derived from acid as well as from basic rocks, though mainly from the latter; and they show other alteration-characters. At the mouth of the Vandrani valley there are exposed in the river-bed coarse palagonite-tuff sandstones containing a little lime, and probably a few tests of foraminifera.

Reference may here be made to the mountain of Ravi-koro which, when seen from the north-east, rises up as a partially independent peak, with a broad base and a conical truncated summit, immediately west of the track followed in the descent from the summit of the range to Vandrani. It is probably not much under 2,000 feet in height, and exhibits bare precipitous cliff-faces on the north side. It would be worthy of the attention of the future investigator.

Recurring to the principal features of the range between Mbale and Vandrani, one may remark the extensive occurrence of basic agglomerates and tuffs on both slopes, the prevalence of olivine-basalts, the frequency of the semi-vitreous and vitreous or rather pitchstone condition of these rocks, and their semi-ophitic character, especially on the summit and north slopes. From the vesicular structure of the rocks of the Koro-tini Bluff and from the character of its tuffs and agglomerates, it is to be inferred that they are the direct products of eruptions, probably in shallow seas.

On the other hand, the tuffs (often foraminiferous) as well as the agglomerate-tuffs of the north and south slopes of the range are in part suggestive of marine erosion. Intrusive masses of basalt are to be observed occasionally, and doubtless to this cause may be attributed the concretionary structure of the tuffs in places, and the alteration of these deposits in one or two localities, where they are penetrated by cracks filled with chalcedony.

(3) TRAVERSE OF THE KORO-TINI RANGE FROM VATU-KAWA TO VANDRANI.—On leaving Vatu-kawa¹, which is not more than 50 feet above the sea, the ascent for the first 600 feet up the steep mountain-side lies along the rocky bed of the Wai-ni-ngio River, which from its rapid fall has more the character of a torrent. On its sides are exposed basic agglomerates and agglomerate-tuffs; whilst the large boulders in its bed are composed of a somewhat altered olivine-basalt. At 600 feet the track abandons the stream-course for the steep mountain slopes, and thence up to 1,100 feet similar agglomerates and tuffs prevail. At this last-named elevation there are displayed fine and coarse indurated palagonite-tuffs, a little altered in character and with little or no lime. A specimen of the former, of which the materials composing it do not exceed .2 mm. in size, shows in the slide an occasional "Globigerina" test filled with palagonitic debris. Such a marine deposit is evidently not of shallow-water origin. The coarser tuff is made up of compacted sub-angular fragments, not over 2 mm. in size; but contains no organic remains. The prevailing rocks exposed between 1,100 and 1,900 feet, a little below the summit of the range, are somewhat altered compacted non-calcareous breccia-tuffs, composed of sub-angular fragments 5 or 6 mm. in size, of a more or less glassy and often vacuolar basic or basaltic andesite, only in part palagonitised, the vacuoles as well as the interstices between the fragments being sometimes filled with a zeolite.²

¹ On the right side of the river close to Vatu-kawa there are some cliffs displaying a section of the mountainous spur, referred to on p. 151, that separates the valleys of the Mbale-mbale and Vatu-kawa rivers, an exposure quite apart from the rocks exhibited on the adjacent southern slopes of the main range. These cliffs are formed of bedded grey tuffs marked by single layers of blocks 6 to 8 inches across and dipping about 30° S.S.W. The tuffs in their texture are not unlike sub-aerial tuff-deposits. They contain no lime and are composed of basic materials with a little palagonite. They seem to indicate some subsidiary vent, close to the present village of Vatu-kawa, which may have been active shortly before or during the emergence of this district.

² These altered tuffs on the southern slope of this range are described on p. 332.

The summit of the range may be described as a "ridgy" tableland. Though about 2 miles in breadth, its level only varies between 2,000 and 2,200 feet, the inequalities being probably the effect of denudation. Here, as in many other similar localities, on account of the dense forest it was only possible to determine the surface-configuration by the use of compass, watch and aneroid. The prevailing rocks displayed in this region are grey non-calcareous basic tuffs, somewhat altered in character, and composed of fragments usually not exceeding 1 mm. in size of a basic glass, the palagonitic process being masked by other changes. These tuffs often become brownish-yellow through hydration. Tests of foraminifera are enclosed, but they are very scanty.

On the north slopes basic agglomerates and palagonite-tuffs are the predominant rocks down to the foot of the range. A specimen of the tuffs taken at 1,300 feet is calcareous in patches and probably contains tests of foraminifera; but it is too much weathered to enable one to speak with certainty on this point. The interesting feature of this slope is the exposure at 1,600 to 1,700 feet of large blocks of a dark grey hypersthene-augite andesite referred to the orthophyric order of those rocks described on page 290. Lower down (1,000—1,300 feet) occasional solitary blocks of the same rock, but somewhat altered, occur imbedded in the palagonite-tuff. This type of rock which is characterised by the orthophyric structure of the groundmass and by other features is rarely represented in Vanua Levu.

Summing up the general results of this traverse we observe that here, as in other parts of the range, basic agglomerates, breccias, and tuffs, the last however scantily foraminiferous, occupy a great extent of the slopes and summit. The alteration of these deposits on the southern slopes is noteworthy. The only deeper seated massive rocks observed were the pyroxene-andesites above alluded to.

(4) TRAVERSE OF THE KORO-TINI RANGE FROM NUKUMBOLO TO SUENI.—The hot springs at Nukumbolo, which are described on page 24, rise up through agglomerate-tuffs. Around the bathing pools lie large masses of altered palagonite-tuffs which give the first indication of the region of altered rocks that extends from Nukumbolo to the lower slopes of the range, a distance of about three miles.

For about a mile and a half or two miles from this place the track lies through a broken country and does not rise to a height more than 300 feet above the sea. A variety of altered rocks are here exposed in position in the stream courses. Some of them are

fine and coarse basic tuffs showing secondary calcite, quartz and opal, as alteration products. Others are palagonite-breccias with the vacuoles of the altered glass filled with opal. Others again are massive basic rocks, such as fine-textured augite-andesites, or doleritic basaltic andesites, semi-ophitic in character, the plagioclase phenocrysts being more or less occupied by calcitic and other products. The alteration is not always far advanced, but it is sufficiently marked to give a common character to the rocks of the district.

Ascending the lower slopes of the range up to 800 feet one finds the altered rocks still exposed in the stream-courses; but the changes exhibited are not always the same. A specimen from 500 feet looks like a tuff, but in the slide it appears as a semi-vitreous augite-andesite, its substance being penetrated by fine veins of chalcedonic quartz and opal, whilst the same material is developed within the larger plagioclase crystals. Another specimen from 800 feet, which is apparently a tuff, contains so much lime that it effervesces freely with an acid. It was composed originally of fragments of a hemi-crystalline basic rock, of which the plagioclase phenocrysts have been replaced by calcite; whilst the augite and interstitial glass is now represented by viridite and a chloritic mineral. It is to be inferred that at some time hot springs were very numerous in the district between Nukumbolo and the lower slopes of the range, those at Nukumbolo, as far as I know, alone existing in our time.

From a height of 1,100 or 1,200 feet the mountain slopes rise steeply to the summit rather over 2,000 feet in elevation. At the foot are exposed *in situ* aphanitic augite-andesites,¹ which in some specimens show a little alteration in the chalcedonic quartz filling minute cracks, and in one case there is an irregular cavity, $\frac{3}{4}$ inch across, filled with milk-white opal. Another rock exposed at the foot of the steep ascent is a semi-vitreous basaltic-andesite, doleritic in texture and ophitic in structure, but apparently not much changed.² At 1,700 feet is displayed a vesicular basic andesite, semi-vitreous in character, and above this I found a porphyritic basaltic andesite.

The summit of the range is $1\frac{1}{2}$ or 2 miles in breadth and is relatively level, its undulating surface varying in elevation between 1,900 and 2,200 feet. The prevailing rocks exposed on this elevated plateau are vitreous pitchstone-like rocks finely vesicular and scoriaceous, the cavities being filled either with aragonite or with

¹ Referred to genus 16, species A, sub-species 1, of the augite-andesites.

² Referred to genus 9, sub-genus A, of the augite-andesites.

opal. The basic glass, of which they are formed, shows incipient crystals, and begins to fuse in an ordinary flame. One specimen obtained here is a doleritic basaltic andesite, slightly ophitic and containing a fair amount of residual glass.¹ However, the vitreous and scoriaceous character of most of the rocks on the summit is very remarkable. (Similar rocks occur on the top of Mount Thambeyu where the slopes of the mountain are covered with submarine tuffs and agglomerates.) There is a precipitous descent on the north side of the range to Sueni at its foot, massive basaltic andesites being exposed at first, whilst basic tuffs and agglomerates are displayed lower down.

The special features of this traverse of the range are the alteration of the tuffs and massive rocks between Nukumbolo and the lower southern slopes, the variation in character of the basic rocks in the upper southern slopes, the occurrence of vitreous vesicular and scoriaceous rocks on the summit, and the restriction of the ordinary basic agglomerates and tuffs to the northern slopes. Any attempt on my part to explain the structure of this part of the range from the data here given would be futile without comparing them with those obtained from other parts of the range. It will be subsequently pointed out that the difficulties will be in part removed if it is assumed that the submarine palagonite-tuffs and agglomerates, that so often cover the flanks of the mountains to their summits, have been in this case largely stripped off by the denuding agencies.

(5) THE SUENI VALLEY.—My acquaintance with the extreme eastern part of the Koro-tini Range is restricted to the descent of the picturesque valley from Sueni to Koro-utari. It is occupied by a tributary of the Lambasa River, and is bounded on the east side by the lofty slopes of the main range, and to the westward by a mountainous spur that projects far into the Lambasa plains. Sueni lies by the river-side in the midst of mountains which rise steeply on most sides to heights of 2,000 feet and over, and often display precipitous bare faces apparently of volcanic agglomerates. Numerous waterfalls may be observed on their flanks, which, as in other localities, doubtless indicate the occurrence of large intrusive dykes. Sueni is situated about 300 feet above the sea, the descent to Koro-utari at the mouth of the valley, a distance of 3 to 4 miles in a direct line, being about 150 feet.

The river as it flows down the valley from Sueni to Koro-utari traverses a region of basic agglomerates and agglomerate-tuffs.

¹ Referred to genus 9, sub-genus B, of the augite-andesites.

These deposits, as they are displayed in the hill-slopes lying W.S.W. and at the back of Sueni, are composed of blocks of the size of the fist of a vesicular basaltic andesite; whilst the large masses on the surface are made of the same, but non-vesicular, rock. The blocks in the agglomerates between Sueni and Koro-tuari range usually from a few inches to a foot in diameter. A specimen obtained from one of them is made of a partly vitreous basaltic andesite; whilst in another case the rock is an altered basic andesite, the glassy groundmass being largely impregnated with colloid silica looking like opal under the lens.¹

Nearly a mile below Sueni, within a space of less than 60 yards, there are exposed at the river-side in the agglomerates three vertical or nearly vertical dykes, 4 to 6 feet in thickness. They trend roughly N.E. and S.W., and are non-columnar, except in the case of the one farthest up the river, which has rude, transverse joints.² The rocks composing these dykes are somewhat doleritic basaltic andesites, olivine being very rare or absent. The two highest, which are only 15 to 20 feet apart, are made of similar rocks characterised by abundant interstitial glass, and having a sp. gr. of 2.78. The rock of the third dyke, about 50 yards farther down the river, has but scanty glass in the groundmass, the sp. gr. being 2.89. The differences between the two types represented in the three dykes are mainly concerned with the degree of crystallisation, and it is probable that though not contemporaneous they were derived from the same fluid magma which, as we may infer from the proximity and lie of the dykes, was situated at no great depth.³

GENERAL INFERENCE RESPECTING THE KORO-TINI RANGE.
—If we can imagine a line of vents, protruding in some cases

¹ Both these rocks belong to the hypersthene-augite andesites, showing phenocrysts of both monoclinic and rhombic pyroxene. The first belongs to the orthophyric order described on p. 290; whilst the second belongs to the second order (genus 13, p. 287) where the feldspars of the groundmass are lathe-like and in flow arrangement.

² The highest dyke trends N. 48° E. and is inclined from the vertical about 15° N.W. The dyke, 5 or 6 yards below it, trends N. 30° E. and is vertical. The dyke, 50 yards farther down, trends N. 35° E. and is inclined from the vertical about 5° N.W. The inclination was only estimated. The bearings are true.

³ Both the types are referred to genus 1 of the augite-andesites, the olivine, when present, being quite insufficient to give a character to the rock. They however belong to different species according to the length of the feldspar-lathes, which in the doleritic rocks averages .2 mm. and in the other type .08 mm.

above the surface of the sea, that were ultimately worn down to a common level through marine-erosion, and were then largely covered over with submarine tuffs and agglomerates, we should have in our mind's eye the first and most important stage in the formation of this range. If we then assume that there followed a period of emergence characterised by a renewal on a very extensive scale of marine-erosion, during which the agglomerates were mainly formed, and that since that period the sub-aerial denuding agencies have been for ages in operation, we shall, I think, obtain some idea of the history of the Koro-tini Range.

CHAPTER XII

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE KORO-MBASANGA RANGE

AS is illustrated in the accompanying profile-sketch, the relatively level-topped range of Koro-tini gives place at its eastern end to a broken line of mountains, of which the round-topped Koro-tambu, 2,753 feet in height, and the pinnaced Koro-mbasanga,¹ 2,537 feet, are the highest peaks. Further east lies the broad Vuinandi Gap which separates the Koro-mbasanga and Mount Thurston, or Thambeyu, ranges. The twin-peaks of Mount Mbatini, the highest mountain of the island, appear in the background in the sketch, and to the left rises Thambeyu, the second highest summit.

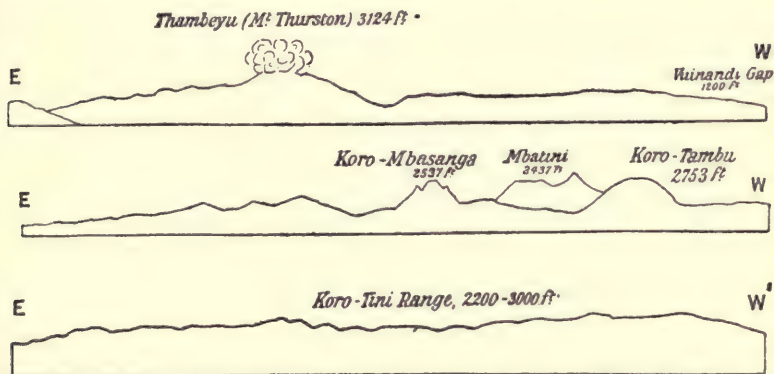
We enter here another complex region of mountains; and if the character of the rocks are sometimes different we shall yet have to bear in mind in our interpretation of its geological features the lesson derived from the examination of the Koro-tini Range. Before and behind all our facts of observation lie the two great periods of marine-erosion and the later ages of sub-aerial denudation.

When approached from the north, the western part of the range has a rude crescentic form, and looks like the remnant of a gigantic crater-cavity about two miles across. At the back rise, as shown in the second of the profile-sketches, the precipitous slopes of Koro-mbasanga proper; whilst the two spurs descending from it, one on the west, the Sokena spur, towards Koro-utari, the other on the east, at the back of Nasawana, give the crescentic

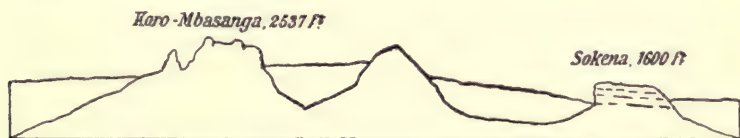
¹ It is pointed out on p. 5 that this name is wrongly applied in the Admiralty charts to Mount Mbatini, a mountain about three miles south of it.

figure open to the north. The last-named village lies nestled in this great hollow, the floor of which, though not in its lowest part below the level of the Lambasa plains, is not over 200 feet above the sea. However, the facts adduced in the following description of this region do not give much support to this view of its surface-configuration.

For the convenience of description, I will first describe the peak of Koro-mbasanga, and then the Sokena ridge and, lastly, the Lovo valley that cuts through the range to the eastward.



These three sections form a continuous profile-sketch of the mountainous axis of Vanua Levu for a length of 15 or 16 miles and include the Thambeyu, Koro-mbasanga, and Koro-tini ranges as viewed from the northward near Na Kama. The eastern section is at the top and the western section at the bottom. The summit of Thambeyu was covered with clouds.



Koro-mbasanga from the north-north-east.

(1) KORO-MBASANGA.—The ascent of Koro-mbasanga is best made from Nasawana, a village at its base, elevated rather over 200 feet above the sea, and distant about a mile and a half north-east from the peak. On the way to the foot of the mountain we traverse an undulating region of basaltic andesite,¹ which is merely the extension to the base of the mountains of the basaltic Lambasa plains. After commencing the ascent of the steep slopes, we find exposed in a stream-course, 700 to 800 feet above the sea, a

¹ Referred to genus 13 of the augite-andesites.

sedimentary basic tuff, presenting layers of coarse and fine materials, and partly palagonitic in composition. It is a little calcareous, and apparently incloses tests of foraminifera. These submarine deposits have evidently been stripped off the basaltic low-lands beneath. It thus becomes evident that the structural features of the Lambasa plains (basaltic rocks overlain by submarine deposits) are preserved to the base of the range.

These submarine deposits, as exposed in the stream-course, lie beneath agglomerates which repose horizontally upon them; and from this level up to the bare rocky peak of the mountain, agglomerates and agglomerate-tuffs are alone displayed either as large detached masses or in cliff-faces.

In the lower part of the mountain the blocks, usually sub-angular, are about a foot across; but they become smaller as one ascends towards the summit, where they are 3 or 4 inches in diameter. At the top there are extensive exposures in cliff-faces of the agglomerate-tuffs; and here the finer materials of the matrix include a few rounded pebbles not exceeding half an inch in size. This is a fact of importance in connection with the submarine origin of these formations.

As regards their composition, the blocks of the agglomerates have not the uniform character we would expect to find in the case of materials directly ejected from a volcanic vent. The most frequent type of rock represented is a grey hypersthene-augite-andesite, having a specific gravity of 2.72—2.78. It displays small phenocrysts of plagioclase and of rhombic and monoclinic pyroxene, but in other respects it exhibits much variety, not only in the arrangement and average length of the felspar-lathes (.08 to .18 mm.) but in the form of the pyroxene of the groundmass (either granular or prismatic) and in the amount of residual glass, sometimes abundant, sometimes scanty. Two distinct genera (1 and 5) of the sub-class are therefore represented.

Other rocks found in these agglomerates contain no rhombic pyroxene, and are referred to genera 13 and 16 of the augite-andesites according to the presence or absence of plagioclase phenocrysts. In the last case we have a dark aphanitic rock (sp. gr. 2.74), sometimes scoriaceous, where the average length of the felspar-lathes may be as little as .04 mm. One of the blocks was composed of a highly scoriaceous semi-vitreous rock, the cavities being filled with a zeolite. Another was composed of a black porphyritic augite-andesite, showing large crystals of plagioclase. . . . The matrix of the agglomerate-tuff is formed of sub-

angular and rounded fragments, up to a centimetre in size, of the same andesites, the interstitial material being formed of fine detritus and palagonitic debris.

Though the agglomerates of the peak of Koro-mbasanga are composed of a variety of rocks, all the rocks are to be referred to the pyroxene-andesites with specific gravity below 2·8 but above 2·7. They are therefore less basic than the olivine-basalts and basaltic andesites of the Koro-tini range, where the density is usually 2·8 and over. Their variation, however, is more consistent with the characters of an agglomerate formed by marine erosion. The same may be said of the sorting of the blocks according to their size and of the occasional occurrence in the matrix of small rounded pebbles. That these deposits of agglomerates were formed under the sea is indicated also by their overlying submarine sedimentary tuffs near the base of the mountain.

(2) THE SOKENA RIDGE.—To the west of Koro-mbasanga, and forming a spur of the same range, is the flat-topped hill of Sokena, which rises about 1,100 feet above the country at its base and about 1,600 feet above the sea. From a distance it has the appearance of being formed in its higher portion of nearly horizontal strata dipping gently northward. In its upper part it terminates in a line of cliffs about 200 feet in height, and there is a similar line of cliffs lower down the slopes. These cliffs are composed of bedded fine and coarse non-calcareous tuffs, dipping about 10° N.N.W., in which are imbedded without any arrangement blocks, ranging in size from 2 or 3 inches to 3 or 4 feet, of a remarkable blackish pitchstone-like rock displaying opaque plagioclase phenocrysts. It is referred to genus 18 (see page 289) of the hypersthene-augite andesites, both rhombic and monoclinic pyroxene being represented in the phenocrysts and in the ground-mass where they take the form of minute prisms (·03 mm.). There is a considerable amount of pale brown glass. A rock very similar occurs in the Thambeyu agglomerates (see page 178). The tuffs are formed largely of palagonitic materials, the angular fragments in the coarser beds being $\frac{1}{2}$ to 2 centimetres in size, the palagonite being often vacuolar but much affected by hydration.

These tuffs and agglomerates of the Sokena cliffs apparently contain no organic remains. They appear to have accumulated under water as the result of the eruptions of a neighbouring vent without the intermediate agency of marine erosion.

(3) THE ASCENT OF THE LOVO VALLEY.—About two miles to the east of the peak of Koro-mbasanga the picturesque Lovo

valley cuts deeply in a southerly direction into the mountainous backbone of the island. The site of the old town of Lovo lies within the valley about two miles from its mouth. "Lovo" is the Fijian word for a cannibal-oven; and I gathered from my natives that in the old times this vale was noted for its cannibal orgies. It is occupied by the Nasawana tributary of the Lambasa River, and often becomes so narrow that it may be described as a gorge. I followed the valley from its mouth, where it is elevated about 300 feet above the sea, for some miles in a southerly direction up to a height of 1,000 feet, where the northern slope of the great mountain-mass of Mbatini commences.

On either side of the Lovo valley rise precipitous mountain-slopes, displaying in their cliff-faces and in the large detached rock-masses basic agglomerates. The same formation is also usually displayed in the sides of the river. The blocks composing the agglomerates are formed of the usual type of hemi-crystalline or semi-vitreous blackish basaltic andesite so characteristic of these deposits. It is generally compact, but is at times amygdaloidal. Some distance below the old site of Lovo, and at an elevation of about 500 feet above the sea, there is an interesting exposure in the river-side, where the agglomerates overlie bedded coarse calcareous basic tuffs containing large flat tests of foraminifera with pieces of molluscan shells, and dipping about 15° S.W. These tuffs can be traced up the valley towards Lovo.

Displayed in mass in the bed of the river in the same locality, and beneath the submarine tuff just referred to, is a porphyritic basaltic andesite (sp. gr. 2.79) containing but scanty interstitial glass, the felspar-lathes being .15 mm. in average length. It is referred to genus 1 of the augite-andesites. The same rock is exposed at intervals in the river-bed as far as Lovo, which is about 850 feet above the sea. At one place it exhibits a rudely columnar structure, the columns being horizontal and 2 to $2\frac{1}{2}$ feet in diameter, the trend of the dyke-like mass being W. by S. and E. by N. Near Lovo a small dyke, 6 feet thick and trending N.N.W. and S.S.E., pierces the agglomerate. It is composed of a somewhat aphanitic augite-andesite closely resembling the rocks exposed in the river-course for a mile or so above Lovo up to an elevation of 1,000 feet. In this upper part of the valley whilst agglomerates are exposed in the cliffs and precipitous mountain-slopes on either side, pyroxene-andesites, somewhat aphanitic in texture and with a specific gravity of 2.68 to 2.7, are displayed in mass in the river bed. These last-named rocks, which are closely similar to those

found on the lower slopes of Mount Mbatini (see page 173) are, as I should have also remarked in the case of the basaltic andesite above mentioned, a little altered, as is indicated by the existence of calcite and viridite in the groundmass.¹

From this instructive ascent of the Lovo valley we may learn that whilst the mountain mass is formed, to a considerable depth, of agglomerates with underlying submarine tuffs, the deeper seated rocks exposed in the river-beds are massive intrusive rocks. The overlying agglomerates have preserved the submarine tuffs from destruction, and there is no difficulty in assuming that they also were accumulated under the sea, but in shallow water, as evidenced by the character of the tuffs. I found no signs of alteration in these tuffs, and except in the case of the small dyke above noticed there is no sign of the dykes penetrating the agglomerates. We have here a section into the heart of the mountain-range; and assuming that the large intrusive masses of basic andesites had penetrated these deposits, there would certainly have been some evidence of this in the extensive exposures of agglomerates far up the mountain-sides. As it is, however, we find such rocks only in the deeply excavated river-bed. If we imagine a submarine volcanic mountain, or one but slightly raised above the surface of the sea, to be subjected during a long period of emergence to marine erosion, the "basal wreck" of the mountain would ultimately be covered over by submarine tuffs and agglomerates. This is the condition that seems to be presented here.

I did not make the ascent of Koro-tambu, the other principal peak of the Koro-mbasanga Range. This round-topped mountain is well seen from the summit of Mbatini from which it bears N. 30° W. by compass. It is probably the peak marked 2,753 feet in the Admiralty chart, and is connected with Mbatini by a saddle not under 1,500 feet in elevation.

Some of the most important features in the above account of this district may here be emphasised. We have seen that in the peak of Koro-mbasanga and in the Lovo valley agglomerates and agglomerate-tuffs, several hundred feet thick, overlie sedimentary submarine tuffs. In the last-named locality the deeper massive basic rocks are also exposed; and we may infer in both instances that the agglomerate-formation is a submarine deposit.

¹ They are blackish and somewhat compact (sp. gr. 2·67—2·71) and have very small felspar-lathes less than 1 mm. long. They contain both rhombic and monoclinic pyroxene, and are referred to genera 1 and 13 of the hypersthene-augite-andesites.

On the other hand, in the Sokena Ridge, which is a spur of the main range, we have apparently the accumulation of materials on a sea-bottom, directly ejected from a vent without the intervention of the agency of marine-erosion. In regard to this and other districts in this part of the island it should be remembered that east and west occur undoubted evidences of extensive submergence. It has already been shown that submarine tuffs containing tests of foraminifera and other organic remains occur at heights of 2,000 feet and over on the summit of the Koro-tini Range, and it will be subsequently shown that similar deposits are to be found on the neighbouring slopes of Thambeyu as high as 2,100 feet.

MOUNT MBATINI

According to the Admiralty chart this is the highest mountain in Vanua Levu, its elevation being 3,437 feet. It has twin peaks which lie either N.W. and S.E. or W.N.W. and E.S.E. with each other. The northerly or westerly peak is pointed and tooth-like. Hence probably arises its name of Mbatini (mbati-tooth). The southerly or easterly peak is known as Soro-levu. It has a broadly conical outline with a truncated summit. The mountain is named Koro-mbasanga in the Admiralty chart, a name that really belongs to a peak lying about 3 miles nearly due north (N. 5° W.). The natives are very clear in this matter; but it must be remarked in this connection that Koro-mbasanga, which signifies "a forked eminence," would be a very suitable appellation for the double-peaked summit of Mbatini.¹ By the natives of the surrounding district the whole mountain is known as Mbatini; but by the natives of the eastern shores of Natewa Bay, it is usually known as Soro-levu, since the western peak is often more or less hidden from view or is less conspicuous. The profile of this mountain and of the neighbouring region is shown in the accompanying profile-sketches and also in one of those illustrating the Koro-mbasanga range on page 167.

As viewed from the top of Mariko to the southward, Mbatini presents itself as a long mountain-ridge, trending W.N.W. and E.S.E., which is connected on the north with Koro-tambu, the highest peak of the Koro-mbasanga Range, by a saddle probably

¹ I discovered this error in a rather practical fashion by ascending the wrong mountain. The natives were engaged to take me to Koro-mbasanga and they performed their task, my aneroid and compass soon indicating that I was not on the highest peak of the island, but on a lesser peak three miles north of it.

not over 1,500 feet above the sea, and on the south with the mountain-ridge of Mariko by a *col* which appears not to be under 1,000 feet in elevation.

My ascent of this mountain was made from the north by the way of the Lovo valley. In ascending the Lovo valley one reaches, at an elevation of about 1,000 feet, the foot of the north

Soro-Lovu. Mbatini 3437?

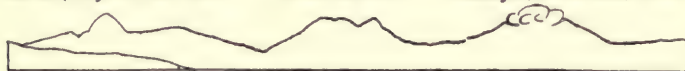


Mount Mbatini from the top of Koro-mbasanga. The distant peak on the right is one of the summits of the Mariko ridge.

Mariko (Drayton Peak) 2890 ft

Mbatini, 3437 ft

Thambeyu (Mt. Thurston) 3124 ft



View from Muanaira on the south coast of Natewa Bay.

slope of Mbatini. The slope is somewhat steep up to 2,000 feet, the rocks exposed on the surface being closely similar in the groundmass to those displayed in the upper part of the Lovo valley. They are compact-looking blackish augite-andesites (sp. gr. 2·7), the very small felspar-lathes of the groundmass, which are in flow arrangement, averaging only ·05 mm. in length. Like the rocks below, they are a little altered; and here the interstitial glass is also scanty. But they differ in the absence of rhombic pyroxene and are therefore referred to the augite-andesites (genus 13).

At 2,000 feet, where one crosses the foot-track from Nukumbolo to Korolau, the ascent of the true Mbatini ridge begins, the summit lying nearly two miles to the south-east. Whilst following along this lofty mountain-ridge we were for the greater part of the time in the rain-clouds, so that very little was seen of our surroundings. The crest is densely wooded so that our progress was very slow. The rocks are but sparingly exposed. At the commencement of the ridge (2,100 feet) is displayed an altered hypersthene-augite andesite, rudely columnar blocks of which, up to 2 feet in diameter, were lying about. It belongs to genus 1 of this sub-class (see page 286) which also includes the rocks exposed farther along the ridge. In these rocks the felspar-lathes are small (·05—·07 mm. long) and are not in flow arrangement. The interstitial glass varies in amount, and the specific gravity is about 2·7.

The ascent is very gradual for the first one and a half miles, when an elevation of 2,600 feet is attained. From here one ascends the steep-sided peak of Mbatini, which rises some 700 or 800 feet from the ridge. As one nears the highest point the crest becomes very narrow, between 15 and 20 feet across; and on either side there is apparently a drop of several hundred feet. The actual peak, which is bare and rocky, is yet narrower; and when it is enveloped in dense mist as it was in my instance, it is not a very secure situation for a geologist. It is highly magnetic, as is the case with most of the other bare peaks of the island. The rocks exposed in the upper 500 feet, that is, in the peak proper, are highly altered semi-vitreous, but extensively weathered, hypersthene-augite-andesites which are referred to genus 1 of that subclass. Much of the glassy groundmass is replaced by viridite, silica, calcite, &c. Less altered specimens display in a brown opaque glass small felspar-lathes averaging less than .1 mm. in length. They exhibit phenocrysts of rhombic pyroxene and augite, the first prevailing.

I did not climb Soro-levu, the other of the twin-peaks. Its ascent should be made either from Nukumbolo or from one of the villages on the neighbouring shore of Natewa Bay. My acquaintance with Mbatini, although very incomplete, enables me however to point out a few of its general features. As remarked before, there is a general uniformity in the type of its rocks. The olivine-basalts and basaltic andesites, prevailing in the Koro-tini Range, are not here represented, nor are the dacites or acid andesites to be found. The characteristic rocks are more or less altered hypersthene-augite-andesites having a specific gravity in the least altered and least vitreous condition of about 2.7; whilst the average length of the felspar-lathes is always less than .1 mm. The same type prevails from the upper part of the Lovo valley to the summit of Mbatini; but it is only in the actual peak that these rocks show much glass in the groundmass, though extensively affected by alteration. Neither tuffs nor agglomerates came under my notice; but they might be expected to occur on the other slopes. I am inclined to regard this mountain-ridge as a huge dyke-like mass or sill, representing the remains of a volcanic vent that has been subjected at different periods to marine-erosion and in later ages to sub-aerial denudation.

THE VUINANDI GAP

I have given this name to the break between the Thambeyu (Mount Thurston) and Koro-mbasanga ranges, where the level of the mountainous backbone of the island descends to about 1,200 feet above the sea. This is the route taken by the track from Vuinandi on the shores of Natewa Bay across the island to Lambasa.

At Vuinandi the mountains recede from the coast leaving a broad level plain extending about two miles inland to the village of Tarawau without rising over 60 feet above the sea. Basaltic rocks are exposed in the spurs that descend from the mountains to the coast on each side of the plain. After traversing the low-lying region that lies between Vuinandi and the main range, one finds on ascending the eastern slopes, *en route* to Lambasa, basaltic andesites of the usual type prevailing up to 1,000 feet. The upper portion of the dividing range, 1,000 to 1,200 feet, is composed of a more compact basaltic andesite which is often rubbly and in this condition is penetrated by fine cracks, $\frac{1}{8}$ of an inch broad, filled with chalcedony. This rock, which has a specific gravity of 2.85, has a very fresh-looking appearance in the slide, and the segregation of silica does not therefore appear to arise from an alterative change. The felspar-lathes, which are in flow-arrangement, average .11 mm. in length, and there is a little residual glass.

The mountains rise on either side of the Vuinandi Gap to about 2,000 feet. Descending on the west side of the range one follows a stream-course down to a level of 400 feet above the sea, agglomerates and coarse basic tuffs being exposed on the way. The rocks forming the agglomerates are for the most part to be referred to genus 1 of the hypersthene-augite andesites. They are sometimes compact and sometimes amygdaloidal, the amygdules being formed of chalcedony and other minerals, whilst the glass of the groundmass is often altered.

The track then lay across a spur, 800 feet in height, principally composed of a greyish porphyrite, exhibiting large opaque crystals of plagioclase, 4 to 7 mm. long, in an almost holo-crystalline groundmass formed of stout lamellar feldspars with large augite granules. It is described on page 268 under the porphyritic sub-genus of genus 2 of the augite-andesites, and is an unusual type of rock for this island. After this I descended into the picturesque

gorge of the Satulaki River, which is only elevated about 200 feet above the sea, agglomerates prevailing. In the vicinity of Satulaki a rather compact basaltic andesite (sp. gr. 2·82) is commonly exposed in position. It is referred to genus 13 of the augite andesites and belongs to the species with felspar-lathes less than ·1 mm. in average length. It occurs both north and south of this place and in the hill-spurs on either side. This is the bed-rock of the Lambasa plains which here begin and extend to the north coast, being usually covered with submarine tuffs and clays.

THE THAMBEYU OR MOUNT THURSTON RANGE

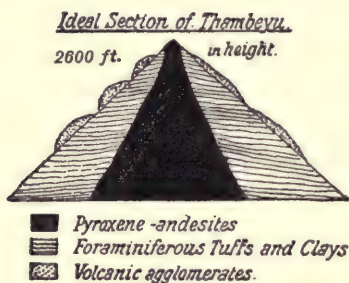
Mount Thurston is the name given in the Admiralty charts to the highest peak (3,124 feet) of this range. There does not appear to be any general native name. The highest peak visible from the Lambasa side is known as "Thambeyu." The lofty mountain-mass, as it is viewed from Vuinandi, is known as Ulu-i-ndiri-ndiri.¹ The whole mountain-range has yet to be properly explored. It is a much more complicated system of mountain-ridges than is indicated in the chart, my acquaintance with it being restricted to the Thambeyu ridge, the elevation of which is 2,600 feet above the sea. It trends N.N.W. and S.S.E.; but its relation to the highest peak of the range could not be ascertained, as we were in the rain-clouds during the two days we were on the mountain.

I made the ascent from the village of Numbu-ni-a-vula about three miles to the westward, which is only 200 feet above the sea. In the intervening low district a basaltic andesite is exposed in the stream-courses. The structure of the ridge, as indicated by the ascent of its western slope, is shown in the accompanying diagram. The core or central axis is formed of massive basic rocks which protrude at the summit and in one or two of the crests of the spurs. The flanks are composed of submarine tuffs and clays overlaid by agglomerates of considerable thickness. The tuffs reach to within 50 feet of the top, whilst the agglomerates extend to within 400 feet of the summit. The results obtained from this ascent are specially interesting, since it afforded me the opportunity of studying in a satisfactory manner the junction of the agglomerates with the tuffs.

There are two caves on the mountain-side which can be used

¹ Vula Votu is the name of a peak lying to the east. Ngoinangai is a forked mountain still further east.

for night-shelter by those exploring the range. The lowest, 1,500 feet above the sea, is the Taloko Cave (na-ngara-taloko). The highest is the Ndromo Cave,¹ 2,100 feet, known to the natives as "na-ngara-vatu-ni-ndromo." Like most of the caves all over the island they occur at the junction of the agglomerates and tuffs, and are to be attributed to the more rapid weathering of the underlying tuffs. . . . In describing the results of my examination of this mountain-ridge, I will deal in succession with the tuffs, the



agglomerates, the junction between these two deposits, and the axis or core of basic rocks.

(1) *The submarine tuffs and tuff-clays.*—As exposed in the stream-courses near and at the foot of the mountain and as high as the Taloko Cave, these deposits are bedded horizontally. At higher levels, owing to insufficient exposure the bedding is not so clear. Up to 700 or 800 feet coarse palagonite-tuffs prevail; but they do not effervesce with an acid, and apparently contain but scanty organic remains. At 950 feet coarse and fine sedimentary tuffs alternate, the last being greenish foraminiferous tuff-clay rocks, somewhat compacted and containing 10 per cent. of carbonate of lime. The tests of the foraminifera, which are abundant and of the Globigerina type, are filled with calcite. Several fragments, of a semi-vitreous basic rock, not however exceeding .2 mm. in size, are inclosed in the deposit; but the mass of it is made up of yet finer materials of the same rock, palagonitic detritus, plagioclase fragments, fine calcitic debris, tests of foraminifera, &c. These fine tuff-clays were evidently formed in relatively deep-water.

At the Taloko Cave (1,500 feet), where there are exposed rather coarse tuffs containing bands about a centimetre thick of a fine clay-tuff, the last-named effervesces freely with an acid, whilst

¹ A kind of "edible" bird's-nest is found in this cave.

the first contain only a little carbonate of lime. No sections have been made of these deposits; but when powdered and examined under the microscope they appear to have the same general composition as the deposit described above from an elevation of 950 feet. They are probably foraminiferous though scantily. The tuffs found at the Ndromo Cave (2,100 feet) contain 4 per cent. of carbonate of lime and small tests of foraminifera are visible with a lens. The mineral fragments include plagioclase and rhombic pyroxene, and there are inclosed rounded gravel-fragments, 5 mm. in size, of a semi-vitreous rock. Palagonitic debris make up the mass of these tuffs. A coarse deposit from 2,500 feet is non-calcareous, but has the same general composition.

(2) *The agglomerates.*—These deposits are best represented in the upper part of the mountain, between 1,500 and 2,200 feet above the sea. Here they often present vertical precipices having a drop varying between 100 and 400 feet, with the submarine tuffs exposed at their base. Such cliffs, however, display no structure. Their vertical faces are to be attributed to joints and to the extensive “slips” that frequently occur on these slopes, when large masses of agglomerate, undermined by the percolation of springs through the tuffs beneath them, roll far down the mountain-sides. The blocks of the agglomerates are fairly uniform in size, being usually 4 or 5 inches across. They are composed of a semi-vitreous hypersthene-augite andesite, containing both augite and rhombic pyroxene, but of an unusual type. It is a blackish rock carrying opaque phenocrysts of plagioclase, and is characterised by the prismatic form of the pyroxene (monoclinic) of the groundmass. A very similar rock from the Sokena agglomerates has been before described. It is referred to genus 18 of the class, and the prismatic sub-order to which that genus belongs is described on page 289.

(3) *The junction of the agglomerates and submarine tuffs.*—This is well displayed at the Taloko Cave. Here the agglomerates lie conformably on the sedimentary tuffs; but the line of junction is sharply defined and the only evidence of transition is afforded by the great diminution in the size of the blocks of the agglomerates, which are 1 to 2 inches across. Immediately beneath the agglomerate is a layer $2\frac{1}{2}$ centimetres thick of a rather coarse sedimentary palagonite-tuff having the composition of the deposits above described, but not effervescing with an acid, and showing no foraminiferous tests. The size of its “grain” is about a millimetre. This passes downward rather abruptly into a chocolate-

coloured marl-like rock, a centimetre thick, which is formed of the same materials but in a clayey condition. Beneath this is the calcareous foraminiferous palagonite-tuff referred to in the first paragraph.

It is apparent that for some time before the agglomerates began to accumulate on the sea-bottom there had been a fairly uniform deposit of submarine tuffs, evidently in rather deep water. Then followed a period during which the finest mud was deposited which is represented by the thin layer of chocolate-coloured clay. This was succeeded by the deposition of coarser sedimentary tuffs forming a layer about an inch in thickness. Then commenced the accumulation of the agglomerates, of which the materials were at first small and afterwards larger in size.

(4) *The core or axis of volcanic rocks.*—This is represented on the summit by masses, 2 to 5 feet across, of two kinds of hypssthene-augite andesite, which are referred to genus I of that sub-class. One is a compact grey rock (sp. gr. 2.72) carrying phenocrysts both of rhombic and monoclinic pyroxene, the former prevailing, and displaying a small amount of interstitial glass. It is magnetic and exhibits marked polarity, as noticed in Chapter XXVI. The other is a scoriaceous rock containing numerous round steam-pores, ranging up to 5 millimetres in diameter and generally filled with clear quartz-crystals and lined by chalcedony. It contains semi-opaque glass in abundance, and is apparently a semi-vitreous form of the rock just described. Both rocks are to some extent altered. . . . On the crest of a spur, 500 feet below the summit, is exposed in position an augite-andesite, assigned to genus 13, sub-genus 1, species B, of that sub-class. It is non-scoriaceous and exhibits a considerable amount of greenish alteration products. (Sp. gr. 2.79.)

THE AVUKA RANGE

This high range, which lies immediately to the east of Lambasa, attains its greatest elevation in Mount Avuka, which is 1,976 feet above the sea. It represents the extension northward to the coast of the inland Thambeyu mountains that culminate in Mount Thurston. In its upper portion Mount Avuka presents bare precipitous faces apparently of agglomerates and some hundreds of feet in height. My acquaintance with this range is scanty. In a traverse from Lambasa to Ngele-mumu I crossed it a mile or more south of Mount Avuka, where it is only 700 feet in elevation.

I also rounded the end of the range where it reaches the coast between Lambasa and the valley of Mbuthai-sau. This last locality, which is described on page 218, derives especial interest from the circumstance that here the regions of basic and acid rocks meet. The basic rocks that occupy nearly all the seaboard from Naivaka to Lambasa here become mingled with, and finally give place to, the acid rocks which prevail in all the region eastward as far as Undu Point.

In crossing the range on the way from Lambasa to Ngelemumu, I noticed as high as 450 feet basic non-calcareous tuffs displaying a concretionary arrangement suggestive of the proximity of an intrusive igneous rock. Further up the western slope occur basic agglomerates, whilst at and near the top (700 feet) there lie on the surface large boulders of a dark grey hypersthene-gabbro having a specific gravity of 2.7 and belonging to the type of plutonic rocks described on page 249. It is very probable that this gabbro forms the axis of the range; and we have here no doubt one of the oldest of the mountain-ridges in the island.

CHAPTER XIII

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE VALANGA RANGE

THIS range, which trends N.W. and S.E. between the Mariko mountain-ridge and the head of the valley of Na Kula, attains a height of 1,880 feet at its N.W. and of 1,710 feet at its S.E. end. The average elevation, however, is probably not over 1,300 or 1,400 feet. My acquaintance with the range is only partial, but it is sufficient to bring to light some of its leading structural features. Those who follow me will find in these mountains a very interesting region for their geological explorations.

(1) TRAVERSE OF THE VALANGA RANGE.—In making the journey from Valanga to Vunimbua, I crossed the range where its elevation was about 1,300 feet. Basic agglomerates, containing sometimes amygdaloidal blocks, are displayed in the low district between Valanga and the foot of the range. In the stream-course at the base of the slope the deeper seated rocks of the range are at once exposed. Large masses, 5 or 6 feet across, of altered grey pyroxene andesites lie in the bed of the stream. Some of them show opaque porphyritic felspar and have the appearance of porphyrites (sp. gr. 2.67). They belong to the type described on page 271 under genus 6 of the augite-andesites. Others are grey propylitic varieties of a basic semi-doleritic andesite penetrated by cracks containing calcite, and displaying in a ground-mass, exhibiting much viridite and a little pyrites, calcitic pseudomorphs of the felspar phenocrysts and more or less parallel felspar lathes, .15 mm. long and somewhat altered. Another of the deeper-seated rocks commonly exposed on the upper west slopes of the range is a dark grey rock showing much porphyritic

pyroxene (sp. gr. 2.72). It has a micro-felsitic groundmass and is referred to the fourth order of the hypersthene-augite-andesites described on page 291.

About two-thirds of the way up the western slope of the range, there is exposed a coarse palagonite-tuff, evidently an incrusting deposit. Stout crystals of augite can be picked out of it, and it contains also lapilli up to an inch in size of a basic vesicular semi-vitreous basalt.

Descending the eastern slopes one observes between 1,200 and 1,000 feet large blocks of the same grey hypersthene-augite-andesite above mentioned and of a grey granitoid rock of the gabbro type. This last is a hypersthene-gabbro with specific gravity of 2.75, and belongs to the group of plutonic rocks described on page 250. Its pyroxene phenocrysts are often represented by fibrous bastite. One can scarcely doubt that this gabbro is the plutonic equivalent of the prevailing grey pyroxene-andesites.

Lower down the slope only small fragments of rocks were exposed, probably derived from an agglomerate. One of the specimens here obtained is a doleritic basaltic andesite (sp. gr. 2.77). Another is a very interesting rock displaying large porphyritic crystals of a mineral like bronzite in a groundmass originally to a large degree vitreous; but the glass is now replaced by viridite and secondary crystalline silica. The "bronzite" is the result of the conversion of associated rhombic and monoclinic pyroxene into fibrous bastite.

From the results of the traverse across this part of the Valanga Range it may be inferred that more or less altered grey basic andesites passing into gabbros chiefly compose it. No doubt at one time it was largely covered with basic tuffs and agglomerates, but these deposits have been almost completely stripped off by the denuding agencies, and were only noticed in one place on the western flank.

That the northern part of the range towards the Mariko ridge has a similar structure is shown by the character of the loose blocks in the upper course of the Vunimbua River, which takes its rise on these slopes. Amongst those in the river above the village I noticed a solitary block of a coarsely crystalline diorite containing prisms of brown hornblende a centimetre in length.¹ But the rocks most frequently represented were propylitic grey hypersthene-andesites, in which the pyroxene is mostly changed into

¹ This rock is described on p. 251.

bastite, whilst the surface often sparkles with pyrites (see page 297).

(2) NGONE HILL.—This is a curious conical hill, about 700 feet in height, that rises up on the right side of the Vunimbua River about $1\frac{1}{2}$ miles above the village of that name and near the foot of the range. It evidently represents a "volcanic neck," and doubtless this vent was the source of the large blocks forming the basic agglomerate that occurs in huge masses in the river-course in the vicinity of this hill. On its lower flanks is exposed a hard compact tuff, showing pyroxene crystals, which is composed principally of fragments of a palagonitised vacuolar basic glass, the minute cavities being often filled with opal. In the upper part of the hill is displayed a massive altered augite-andesite penetrated by fine veins of chalcedony. Numerous irregular cavities filled with the same material occur in its dark opaque glassy groundmass.

The blocks of the agglomerates found in the vicinity of the hill vary in size from 4 to 18 inches. They are composed of a compact blackish semi-vitreous basic andesite (sp. gr. 2.73) of the type characteristic of the basic agglomerates over most of the island. The matrix of the agglomerate is hard and somewhat altered, and is chiefly made up of fragments, ranging up to 5 mm. in size, of a vacuolar basic glass, sometimes but slightly changed, though usually converted into palagonite, the vacuoles being filled with chalcedonic opal. The large masses of coarse tuffs displayed in the bed of a stream-course close to Ngone Hill are non-calcareous and composed of palagonitic materials. Palagonite-tuff clays are also exposed in the river-course a little above Vunimbua. About half-way between the village and the hill there occurs in position at the river-side an amygdaloidal basic rock, the amygdules being formed of chalcedonic opal.

It is apparent that this hill represents a lesser vent which probably dates back to the period before the emergence. All the products of its eruption are, however, more or less altered. From the absence of sorting in the blocks of the agglomerates, and from the character of the matrix, it may be inferred that these deposits have been accumulated directly from the ejected materials without the intervention of the agency of marine erosion.

(3) THE WESTERN FLANK OF THE VALANGA RANGE.—One of the boldest pieces of coast in the island lies on the eastern side of Savu-savu Bay, between the mouth of the Ndreke-ni-wai River and Valanga Harbour. Here a number of lofty headlands separated by broad valleys descend with precipitous fronts to the

shore, some of them, as in the case of the Nambathi promontory on the north side of Valanga Harbour, retaining an elevation of 1,000 feet within a few hundred yards of the coast.

By following the coast-track from the Ndreke-ni-wai River to Valanga one crosses some of these headlands. As far as Vatu-lele altered red tuffs, basic agglomerates, and massive basaltic andesites are the prevailing rocks. The red tuffs exhibit a double alteration. They were originally composed of finely pulverised basic vacuolar glass, which subsequently became palagonitised, and afterwards there was an extensive deposition of chalcedonic silica and of red iron oxide. No organic remains appear to exist; whilst the scanty calcite present is evidently an alteration product. Where the road "tops" the headland on the north side of Vatu-lele Bay, there is exposed a dyke-like mass of a rubbly semi-vitreous basaltic rock penetrated in all directions by veins, 1 to 3 inches thick, of a tachylytic glass, splinters of which fuse readily in the ordinary spirit-lamp flame. The numerous fissures were doubtless produced during the consolidation of the rock; and subsequently they were filled with the still fluid residual portion of the magma, which would be composed of the most fusible constituents. This subject, which bears on the origin of palagonite, is discussed in Chapter XXIV.

Between Vatu-lele and Urata, palagonite-tuffs and basic agglomerates are chiefly displayed. On the north slope descending to Urata there is exposed in the foot-path a dyke-like mass of a dark-grey hornblende-pyroxene-andesite, an unusual type of rock which is described on page 298. Just south of Urata I observed an agglomerate containing large blocks, 3 or 4 feet across, of the deeper-seated altered grey pyroxene-andesites that with the gabbros and diorites form the axis of the range.

(4) THE VALLEY OF NA KULA.—In crossing from Sava-reka-reka to Natewa Bay, one ascends the remarkable valley of the Kula and traverses the ridge at its head. This ridge, which is about 700 feet in height and forms the termination of the Valanga Range, is composed of altered grey hornblende-pyroxene-andesites and of similar holo-crystalline rocks representing the gabbro or plutonic type of the same. One of these rocks is described on page 250, under the head of hornblende-gabbro. Another is referred provisionally to the hypersthene-gabbros (page 249); but it is extensively occupied by chlorite, viridite, and other alteration products. Here, as with the other rocks of the Na Kula Ridge, the plagioclase phenocrysts are opaque, the result of the numerous

fine cracks with decomposition products in the interior of the crystals. . . . It is thus seen that in general structure the Na Kula Ridge represents the main axis of the Valanga Range to the north.

The valley of Na Kula is occupied by a river which does not empty itself, as one would expect, into Savu-savu Bay, but turns off sharply to the south at right-angles to its previous course, and after breaking through the coast range, opens into Naindi Bay. This peculiarity has attracted the attention of the natives. The village of Sawa-Ndrondro, which lies about $1\frac{1}{2}$ miles up this valley, is not elevated more than 50 feet above the sea. The gradient is evidently not only very slight but is also irregular, so that in their upper course about 3 miles inland, where the elevation is only 130 feet, the waters of the river are partially checked in their flow and form extensive swamps where the "vitho" or wild sugar-cane flourishes.

(5) CONCLUDING REMARKS ON THE VALANGA RANGE.—It may be inferred from the geological structure of the range that it is one of the oldest in the island. The agglomerates and tuffs that enter so largely into the formation of most of the other mountain-ridges are here to a great extent absent, except in the lower flanks; and we have exposed the axis of the range composed of more or less altered grey pyroxene and hornblende-pyroxene andesites passing, as appears to be the case, into gabbros and diorites. It is true that the exposure of the gabbros is limited and that only a single block of diorite came under my notice; but this might be looked for where the plutonic rocks are deeply seated. Although far overtopped by the neighbouring agglomerate mountain-ridge of Mariko, the Valanga Range would seem to date back to a much earlier stage in the history of the island.

THE MOUNTAIN-RIDGE OF MARIKO

This mountain-ridge, which trends nearly east and west and joins the Valanga Range, rises in mass to a height of rather over 2,000 feet. Above this elevation it terminates in several short conical peaks, of which the highest, 2,890 feet, is named Mariko, the Drayton Peak of the chart. One of the peaks, lying a little to the east of the summit, and apparently between 100 and 200 feet lower, is called the Vatu-mbutho or White Rock. In the profile of the range, as seen nearly "end-on" from the distant south shore of Natewa Bay, it would appear to be rounded in its upper part. Its true outline, however, when viewed in length, is, as described above, namely, a massive ridge with various peaks.

When viewed from the top of the hills behind Valanga, this mountainous range has a very imposing appearance. On the south side it rises precipitously to the summit, but the northern slopes below an elevation of 1,800 or 1,900 feet descend with a very easy gradient for $1\frac{1}{2}$ or 2 miles into the valley of the river Ndreke-ni-wai. In the first case the average angle of the slope would be from 15 to 20 degrees and in places often more; whilst in the second case the average inclination would be about 7 degrees. The contrast between the two sides of the range is very striking and one ought, I think, to find a parallel in the broken-down rim of a large crater with a gentle outer slope and a precipitous inner face. When descending recently the outer slope of Monte Somma, the ancient Vesuvian vent, I found reproduced some of the features of the northern slope of Mariko. The tuffs and agglomerate-tuffs that cover their outer flanks are in both mountains deeply scored by the gorges and ravines worn by the torrents. After the description of the geological structure of the Mariko Range, we shall perhaps be in a better position to consider this question; but until a proper survey of the region has been made it will not be possible to give a final answer. There are also many other uncertainties which would be removed by the accurate mapping of the district, such for instance as the mode of connection between the Mariko and Valanga Ranges.

The highest peak of the Mariko Range is irregularly square-topped and is only a few paces across. It has a soil-cap and supports small trees and shrubs, whilst there is a precipitous rocky face on the east and south. Like most of the other lofty peaks of the island it is magnetic, and as remarked on page 368, it markedly deflects the compass-needle.

I made two ascents of this mountain from Vunimbua, one to the highest peak (2,890 feet), and the other across the range to Nukumbolo at a point half a mile or more to the west of the summit, where its elevation is 2,200 feet. Basic agglomerates and agglomerate-tuffs prevail on both the slopes up to 1,800 or 2,000 feet, the blocks being composed of a dark semi-vitreous basic andesite referred to the hypersthene-augite sub-class with specific gravity 2.75. It contains much glass in the groundmass, and since the pyroxene of the groundmass is prismatic, this rock belongs to the prismatic sub-order described on page 289. Ordinary basic tuffs are also well represented on the north flank. On the south or precipitous side they are usually more or less altered. Here, for instance, they may take the form of a hard breccia-tuff containing

vesicular lapilli, up to half-an-inch in size, of a semi-vitreous basic rock, the small steam-holes being either empty or filled with opal or chalcedony. The matrix of the rock is made up of finer fragments of a basic vacuolar glass, showing a few felspar micro-liths, but often more or less palagonitised. Evidence of further alteration is afforded by the small cracks and crevices filled with chalcedony.

Other altered tuff-rocks are exposed on the south slope. At an elevation of 400-450 feet above the sea, and underlying the agglomerates and breccia-tuffs, I found exposed in a stream-course a hard dark rock looking like a compact andesite. Under the microscope, however, it is shown to be an altered palagonite-tuff composed in part of angular fragments of plagioclase and of rhombic and monoclinic pyroxene, not exceeding 15 mm. in size, and containing also similar-sized fragments of a basic hemicrystalline rock. The base is made up of palagonitic material and contains a few "Globigerina" tests sometimes displaying calcite in their interior. Fine cracks filled with chalcedonic silica testify to a subsequent alteration of the deposit. At 1,500 feet occurs a hard red altered palagonite-tuff, having a similar composition and being altered in like fashion, but not displaying tests of foraminifera in the slide.

The foregoing remarks refer to the main undivided mass of the range, that is, up to 2,000 feet. The highest peak of Mariko probably represents in structure the other peaks rising to various heights on either side of it. Here, at elevations between 2,000 feet and the summit, a rubbly agglomerate prevails of a somewhat different character from that occurring at lower levels. It is well exposed in some cave-cliffs at a height of 2,500 feet and also in the rocky face of the peak. The rock composing the blocks is a dark-grey aphanitic augite-andesite (sp. gr. 2.65), referred to genus 20 of that sub-class and displaying prismatic pyroxene in the ground-mass. Smoky residual glass exists usually in fair amount; whilst in the blocks of the cave-cliffs it is so abundant that the rock may be termed semi-vitreous. In the locality just named the blocks are scoriaceous, the steam-pores, which are drawn out to a length of 5 or 6 mm. and more, being partially or completely filled with calcite and occasionally with opal. At times the steam cavities are much larger. In one of my specimens there is an elongated cavity 5 cm. (2 inches) in length, which has a thin lining of chalcedony, from the surface of which pyramidal crystals of calcite project into the interior. (I found the same grey andesite exposed *in situ* lower

down the south slope at an elevation of 1,800 feet, but non-scoriaceous.) The matrix of the agglomerate principally consists of fine palagonitic material with small fragments of plagioclase and pyroxene but apparently no lime.

At heights of about 2,800 feet on the south side of the peak, and of 1,600 feet on the north flank of the range, are exposed non-calcareous greyish tuffs remarkable for the quantity of crystals of rhombic pyroxene, entire and in fragments, that they contain. This is a characteristic feature of the more acid andesitic tuffs of the island, and it is to these deposits that the Mariko tuffs in question make a near approach. They contain at times subangular fragments of more basic rocks; and are true tuffs in the sense that although perhaps deposited on a sea-bottom they represent the ejected materials of a subaerial vent.

The crest of the range, where it is crossed by the road from Vunimbua to Nukumbolo and for 200 feet below, is formed of a decomposed rock, perhaps a breccia. A fragment of the rock obtained from the crest is a grey somewhat altered hypersthene-augite andesite (sp. gr. 2.75) with an orthophyric groundmass, and referred to the order described on page 290. This rock may be connected with the tuffs above alluded to Reference may here be made to a black basaltic rock (sp. gr. 2.88) of which, at an elevation of 2,500 feet at the foot of the peak, I found a portion of a columnar block about 18 inches across. It may prove to be an olivine-basalt; but no section has been made of it.

It is apparent from the foregoing description of the Mariko Range that in general structure it does not differ materially from the other mountain-ridges of the island, although in the types of the rocks it presents some variety. Here also we have agglomerates prevailing on the flanks and forming the summit. As far as the characters of the rocks can guide us, we cannot determine whether the range has been built up by a number of vents on a great fissure, or whether it represents the remains of a huge crater. In this uncertainty we can only appeal to the contrast between the gentle gradient of the north slopes and the precipitous descent of the south slopes as favouring the last supposition. We cannot, however, doubt that the agglomerates of the upper portion of the range are the products of an eruptive vent or of vents that rose above the surface of the sea, since the blocks are all of one kind of andesite and are often scoriaceous. We can be fairly certain that at such a time the lower slopes were in part submerged, seeing that foraminiferous tuffs underlying the agglomerates are now exposed. But we have to distinguish between these

submarine basic tuffs of the lower slopes which may in part be the result of marine-erosion and the grey rhombic-pyroxene-tuffs of the upper levels which are probably derived from subaerial eruptions.

THE SAVU-SAVU PENINSULA

I include in this district the promontory west of Naindi Bay and Sava-reka-reka Bay. Although its surface is much cut up, it has, when viewed from a distance, a fairly even profile and attains a maximum height of rather over 800 feet. From the region east of it, it is separated by the Naindi Gap. Here one can cross the peninsula between the two bays above named without rising more than 50 feet above the sea. The elevated interior is divided into two parts, which are divided by a *col*, about 250 feet in elevation, which is ascended in crossing from Naithekoro on the south coast to Na Kama on the north coast. Much of the surface is clothed with the usual "talasinga" vegetation. Close to the north shore, with which it is connected by the reef-flat, rises the small island of Na-Wi, and off the extremity of the peninsula, which is known as Harman's Point, is the islet of Naviavia, formed of raised reef-limestone as described on p. 8. The celebrated boiling springs known as Na Kama are situated on the north coast opposite Na-Wi. It may be remarked in passing that besides finding an exit in the springs, the hot water oozes through the beach and below the tide-marks for several hundred yards along the shore. These springs are described in detail on p. 25.

This is one of the few districts of the island in which elevated reef-masses occur at the sea-border. These old reefs, which attain a maximum elevation of 250 feet above the sea, are principally restricted to the neighbourhood of Naindi Bay. (They are referred to in detail in Chapter II.) But they indicate only a part of the submergence which this region has experienced. There is an exposure of a very interesting rock in a stream-course that is crossed on the road from Yaroi to Naindi, less than a mile from the first-named place, and about 30 feet above the sea. Here we find a dark, impure "Globigerina" limestone, or, as it might be also designated, an altered calcareous palagonitic clay-tuff.¹ The larger fragments in it average only .2 mm., and it affords evidence of a period of submergence during which the hill-tops of the Savu-savu Peninsula were below the sea-level.

We get the same indication, but in a more pronounced degree,

¹ It is described under Sample C on p. 325.

in the stratified sedimentary clay-tuffs which are exposed on the shore-flat of the south side of the neighbouring Sava-reka-reka Bay. These beds, which within a distance of fifty paces are inclined 10—15° to the south-west and the same amount to the north-west, have apparently a quâquâversal dip. In places they exhibit a spheroidal and concentric structure, and are penetrated by cracks containing some calcite, but mostly filled with a white zeolitic mineral.¹ One of these rocks is a bright green, hard and compact deposit, containing but little lime, and evidently an altered palagonitic clay-tuff. It contains a few minute tests of the "Globigerina" type; and on account of the small size of its fragments of minerals, which range from .01 to .04 mm., it may be regarded as a relatively deep-water sediment.² It is interstratified with a coarser, somewhat altered palagonite-tuff, which shows but little lime and only a suspicion of tests of foraminifera. The size of the larger included fragments does not exceed half a millimetre. The low hill, near Yaroi, on which the magistrate's house is built, is composed of fine and coarse tuffs, probably submarine. It is doubtful whether any but sedimentary tuffs occur in this peninsula.

In the hills of the western part of the peninsula, that is, west of Na Kama and Naithegoro, a particular type of basaltic andesite prevails, characterised by rhombic pyroxene as well as augite phenocrysts, and referred for the most part to genus 13 of the hypersthene-augite andesites. Their specific gravity ranges from 2.76 to 2.83, and the interstitial glass may be fair or scanty in amount. The average length of the felspar-lathes is unusually small, .04—.06 mm. In these respects the basaltic andesites of the Savu-savu Peninsula differ from the basaltic andesites found in most other parts of the island, where, as exemplified by those of the Wainunu, Solevu, and Seatara regions, the felspar-lathes average between .1 and .2 mm. in length, and there is practically no rhombic pyroxene. A somewhat scoriaceous semi-vitreous form of pyroxene andesite is exposed on the south slopes above Nukumbalavu, where it is covered by basic agglomerates. The pyroxene in the groundmass is here prismatic, and not granular, and for the most part rhombic; and the rock is referred to the prismatic sub-order of the hypersthene-augite andesites described on p. 287.

¹ It is granular, but fuses in the blowpipe flame into a clear glass and gelatinises in HCl. Probably a form of natrolite.

² It is described under Sample D on p. 326.

The basaltic andesites of the peninsula are often extensively decomposed through the weathering process, a spheroidal structure being then displayed. It rarely happens that the basaltic rocks of this locality assume a propylitic character. Yet, if this change is due to hydrothermal metamorphism, we ought to find altered rocks of this kind in the vicinity of the boiling-springs. Such rocks did not come under my notice at the surface ; but this only indicates that if this alteration has taken place here, it has been effected at some depth ; and, indeed, it would seem probable that the alteration known as "propylitic" is a change produced generally in deep-seated rocks.

A semi-ophitic basaltic andesite that is exposed in the small stream-course at the back of the springs, and not 100 yards distant, displays no propylitic change, and is only affected by hydration. The basaltic andesites found on the hill-slopes further inland from the springs exhibit no change of such a nature. However, rocks of this description occur at and near the coast about a mile to the westward. One of them, which is light green in colour, might be taken for a limestone, since it effervesces with an acid. When examined in the slide it is shown to be the prevailing basaltic andesite greatly altered. The porphyritic rhombic pyroxene is replaced by viriditic material ; the plagioclase phenocrysts are replaced by calcite, secondary silica, and other alteration products ; and the structure of the groundmass is disguised by chalcedony, calcite, viridite, &c. Another rock from this locality displays great alteration. The structure of the groundmass is obscured by secondary silica, and is traversed by fine cracks passing through the felspar phenocrysts and filled with blood-red films of hematite.

On the hill-slopes behind Harman's Point, at an elevation of 300 to 400 feet, blocks of a reddish, volcanic rock, greatly altered by the deposition of silica, were displayed on the surface. The ground was here strewn in places with beautiful pyramidal prisms of clear quartz, ranging up to an inch in length. They contain numerous inclusions, their faces being sometimes deeply etched or eroded. These crystals appear to have been formed rather rapidly in some highly siliceous thermal underground waters.

I did not ascend the hills of the portion of the peninsula lying east of Na Kama and Naithekoro. But whilst crossing the saddle between these two places, I perceived that the prevailing basaltic andesites extended up the slopes to the east. The neighbourhood of Naindi Bay offers several features of interest. The bay, which is circular in shape, is closed in on the east and

west by projecting points, where we find elevated reef-limestone, 40 or 50 feet above the sea, displaying massive corals and large "Tridacna" shells in their natural position, and overlaying a cement-stone composed of blocks of volcanic rocks in a calcareous matrix. On the beach on the west side of the bay there is exposed a reddish-grey altered pyroxene-andesite, which, as regards the size of the feldspars of the groundmass and other characters, appears to be an altered form of the prevailing basaltic andesites of the peninsula. In the midst of the low passage that isolates the peninsula, which I have termed the Naindi Gap, there is displayed a highly altered basic andesite which contains a white, zeolitic mineral in its numerous cracks.

The small island of Na-Wi consists of two low hills, the highest 130 feet in height, connected by a mangrove swamp and a sandy beach. There is no trace of a crateral cavity. The prevailing rock is a porphyritic, compact, basic andesite, differing from the other rocks of the neighbourhood in the greater amount of glass it contains. Though it is not easy to find a good, unweathered specimen of the rock, it would appear that Na-Wi represents an old volcanic neck.

We may infer from the above description of this peninsula that it has a history similar to that of most other parts of the island. There is evidence in the upraised reefs and in the "Globigerina" clays and limestones of considerable submergence at one period; and it is highly probable that the prevailing basaltic andesites are the products of submarine eruptions. In my account of the hot springs given on page 26, reference is made to the absence of any trace of a crateral cavity in that locality. The same is true, as far as my observation goes, of the whole peninsula. Altered rocks do not occur in the vicinity of the springs, but they are to be found at distances a mile and more away. It does not seem possible to restore in imagination the original form of this part of the island. The present contours are the results of more than one reshaping of the surface through the agencies of marine erosion and sub-aerial denudation.

THE DISTRICT BETWEEN NAINDI BAY AND THE SALT LAKE

Three or four of the peaks of this hilly district rise to about 1,000 feet or rather over, the highest being that of Na Suva-suva, which attains a height of 1,110 feet. Since my acquaintance with this region is incomplete, I will confine my remarks to the localities actually examined.

Through the kindness of Mr. F. Spence, I was able to make use of a track cleared to the top of Na Suva-suva. This eminence, which forms a conspicuous landmark for many miles, both landward and seaward, has a rounded summit and is to all appearance an old volcanic neck. It is composed in mass in its upper half of a heavy dark olivine-basalt (sp. gr. 3.01), seemingly non-columnar, and referred to the highly basic rocks forming genus 16 of the olivine-basalts. There is such a thick soil-cap on the lower slopes that I was unable to ascertain the character of the rocks there. It is, however, noteworthy that a very similar olivine-basalt (sp. gr. 2.99) crops out on the coast south of this hill and to the east of Naindi Bay. They both contain abundant small olivine-phenocrysts and a little residual glass, the felspar-lathes averaging .1—1.4 mm. in length. Since their localities are rather more than a mile apart, it is not possible to say without a further examination of the locality whether or not we have here the same intrusion.

On the coast between Naindi Bay and Salt Lake Passage, calcareous tuffs, probably fossiliferous, are occasionally exposed in the low spurs descending to the sea, whilst islets of elevated reef-rock front the beach.

The coast immediately west of the Salt Lake Passage is of exceptional interest. Here the sea-cliffs and the shore-flat are formed of an agglomerate tuff penetrated in all directions by veins of calcite, an inch and under in thickness. The matrix of this deposit, which is a little calcareous, is principally made up of fragments, ranging up to 3 or 4 millimetres in size, of vacuolar palagonite, the minute vesicles being filled with some alteration product. It also contains large macled augite crystals 5 or 6 mm. in size, which can be picked out in numbers by the fingers. The blocks vary from a few inches to two feet across, and are usually composed of an augite-andesite, containing large porphyritic crystals of augite, and are often amygdaloidal, the amygdules, 3 or 4 mm. in size, being formed of a zeolite. But blocks of very different rocks also occur in this agglomerate tuff. One, about two feet across, was composed of a coarsely crystalline diorite made up, as described on page 251, of large crystals of hornblende, 2 to 2.5 centimetres long, and of large opaque crystals of acid Labradorite. Another was made of hornblende-hypersthene andesite belonging to the ortho-phyric order of that sub-class (see page 299). There is a little altered glass in the groundmass, and large secretions of brown hornblende, more than an inch in size, are to be observed in the rock.

It is probable that this singular deposit represents a submarine accumulation of materials ejected from some neighbouring vent. Organic remains did not come under my notice; but apart from the palagonitic character of the matrix and the abundance of veins of calcite, the submarine origin is indicated by the existence of upraised reefs in the coast districts east and west of this locality. The block of diorite affords an important clue as to the character of the deep-seated plutonic rocks in this part of the island. A similar diorite was found by me amongst the blocks in the bed of the Vunimbua River; and on page 185, reference is made to the probability of such rocks forming the nucleus of the Valanga Range.

The hills on the west side of the Salt Lake are worth further examination. On the coast of the Natewa Bay side of this district, in the vicinity of Vuni-tangaloa and between that place and Vuni-sawana, there are displayed agglomerates formed of blocks of hornblende-andesite, some of the specimens being very similar to that obtained from the block of hornblende-andesite noticed in the agglomerate-tuff on the neighbouring south coast.

THE SALT LAKE

The low isthmus, about $2\frac{1}{2}$ miles in breadth, which connects the Natewa Peninsula with the rest of the island, can be crossed without rising more than 40 or 50 feet above the sea. From the occurrence of upraised reefs in the islets and in the low sea-cliffs of the south coast it may be inferred that at no distant period in the history of Vanua Levu this isthmus was submerged.

The lake, which is oblong in form, is about four-fifths of a mile long and about two-fifths broad. Its maximum depth according to the Admiralty chart is 3 fathoms; but the usual depth in the centre varies, as I found, between 2 and $2\frac{1}{2}$ fathoms. It communicates with the sea on the south coast by a long narrow passage, rather over a mile in length, which for the greater part of its course, excepting near its seaward mouth, is only between 25 and 30 feet broad. Mangroves flourish around the lake and also line the passage; whilst elevated reef-rock is to be observed on the sides of the passage. Mr. Horne was informed that corals abound in the lake-waters; but I find no reference to this point in my notes. Judging from the density of the effluent water, the specific gravity of the lake-water is that of the sea. The "rise and fall," as noticed below, is considerably less than in the case of the tides at the coast.

Near the centre of the lake there is a low islet, some 40 paces across, and only raised about a foot above the level of the lake at the time of high-water. It is chiefly made up of coral blocks ; but there are a few fragments of basaltic andesite lying about, which were probably brought there by natives. This islet is mentioned in Mrs. Smythe's account¹ of the visit made by Colonel Smythe to the lake in 1860 ; and by reason of its little elevation it may be accepted as a rude datum-mark of the relative level of land and sea in this region. From this it would appear that there has been no appreciable change of level in this region for the last forty years.

Except on the north and north-west sides, the lake is more or less surrounded by hills reaching up to 400 or 500 feet, the passage representing a break in the range. On the Natewa Bay side the level of the surface is much lower. The low strip of land that intervenes between the north-west corner of the lake and Natewa Bay is about a mile across, and does not attain a greater elevation than 40 or 50 feet above the sea. On its surface, fragments of basic volcanic rocks are displayed ; but no reef debris came under my notice. At its north-east side the lake is only separated from Natewa Bay by a neck of land 300 to 400 yards in breadth and about 100 feet high. It was across this neck that the natives in old times used to drag their large canoes.

Mr. Horne² who visited this neighbourhood in 1878, suggested that the Salt Lake occupies a crater-cavity. The hills around are of volcanic formation, and I am rather inclined to support this view ; but certainty is scarcely possible now, on account of the great degradation which the surface has evidently experienced during and since the emergence ; whilst subsequent reef-growth has also to some extent masked the original form of the district. It is noteworthy that a somewhat parallel condition of things is presented a few miles to the west by the circular Naindi Bay and the low passage, not more than 50 feet above the sea, that partly isolates the Savu-savu Peninsula.

The peculiar behaviour of the tides in connection with the Salt Lake and its passage attracted my attention during two visits to this locality. On the first occasion I noticed that between two and three hours after the tide at the coast had commenced to rise there was still a strong flow through the passage from the lake, and that the current was only reversed in the latter half of the

¹ *Ten Months in Fiji*, London, 1864.

² *A Year in Fiji*, pp. 154, 169 ; London, 1881.

rising tide. During my second visit at the end of May, 1899, when I was accompanied by Mr. Smallwood, I spent a night in observing the behaviour of the spring tides at a spot below the narrow portion of the passage 600 or 700 yards from the opening on the coast. Here the breadth was about 100 feet, the depth at low-water 5 feet, and the rise of the tide 4 feet. The current ran seaward at a velocity varying from 1,500 to 2,500 yards per hour ; and it continued to flow in this direction for $2\frac{1}{2}$ hours after the tide had begun to rise on the coast. (In the narrow part of the passage the rate of the current would probably be not over 3 knots.) It is curious that at the place of measurement the bottom was formed of mud into which the pole sank six feet without striking a hard substratum. The observations on the current were made with a vertical float immersed about 3 feet.

The point of difficulty in the behaviour of the tides is this. The water is running rapidly out of the lake for nine hours ; whilst during the remaining three hours there is a sluggish return-flow up the passage into the lake. A far greater quantity of water finds an exit by the passage than is returned by the same channel ; and I can only explain this by assuming that there is an extensive percolation of water from Natewa Bay into the lake. It is easy to show that with such a narrow effluent, which cannot have a sectional area exceeding 180 square feet, the level of the lake would be only lowered 2 or 3 feet, if the average velocity during the nine hours was two nautical miles. The great bulk of the water would thus remain unchanged. The ultimate result of such conditions would be a lake of brine. Since, however, the sea-water of the lake possesses the ordinary density, it is apparent for this reason only that there is some other means of supply than by the present narrow passage leading to the sea. The mean level of the Salt Lake is evidently rather above that of the sea, perhaps a foot or two ; and the "rise-and-fall" is probably very small.

CHAPTER XIV

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE NATEWA PENINSULA

THIS remarkable peninsula is connected with the rest of the island by the low-lying Salt Lake district, a narrow isthmus, described in the preceding chapter, which one can cross without rising 50 feet above the sea. My acquaintance with this region is far from complete; but from the following notes a fair general idea of its geological characters may be gathered.

By referring to the map it will be seen that there are three groups of mountains. The north-eastern culminates in Mount Freeland or Ngala, 2,740 feet; the southern is formed by the rugged Waikawa Range, 1,540 feet; whilst the Lea Range to the west attains in Ngalau-levu a height of 1,960 feet. They are much cut up by the denuding agencies, and all bear the stamp of an ancient land-surface. Though hot springs are not infrequent, as at Ndreke-ni-wai, Waikatakata, Ndevo, and Navuni, no evidence of recent volcanic action came under my notice. Submarine deposits occur at intervals on the surface up to elevations of 1,000 feet and over; but with the exception of the comparatively recent upheaval or emergence of some 20 or 30 feet, indicated by the raised reef-masses and foraminiferous tuffs and clays in different parts of the coast, there is nothing to suggest that these changes did not occur ages since. In the frequent alteration of its andesitic rocks, and in the occasional occurrence of porphyrites, we have sufficient indication of the antiquity of this part of the island as far as its volcanic history is concerned.

I will commence the description of this peninsula at its western end.

The broken elevated district that extends eastward from the Salt Lake to Fawn Harbour on the south coast, and to the mouth of the Ndreke-ni-wai River on the north coast, is divided into two principal masses, which are connected by a ridge or *col* about 400 feet above the sea, which is situated a little east of Viene. The western portion, which may be named the Viene sub-district, attains a maximum height of 1,000 feet. The eastern portion reaches in the peak of Ngatau-levu, a height of 1,960 feet, and may be termed the Lea sub-district.

THE VIENE SUB-DISTRICT.—The cliffs on the north coast between Muanaira and a little east of Viene are mainly formed of basic tuffs, often calcareous. At a place about $1\frac{1}{2}$ miles east of Viene, these tuffs as exposed in a coast spur display large flat spiral tests of shallow-water foraminifera 4 or 5 millimetres across. They may be described in this locality as palagonitic calcareous tuff-sandstones, more or less compacted, and containing fragments of palagonitised basic rocks. When crossing the *col* above referred to one finds similar palagonitic calcareous sandstones and clays exposed on its slopes up to its summit (400 feet).

On the south side, in the vicinity of Vunilangi Inlet, foraminiferous clays and reef-limestones are displayed at the foot of the slopes; and the coast between this place and Tathelevu to the westward is bordered by low cliffs of reef-limestone raised 6 to 8 feet above the high-water mark and displaying massive corals in their position of growth. Near Tathelevu there occur raised reefs 10 to 15 feet above the sea; whilst the hills, 250 to 300 feet in height, at the back of this place are composed of fine and coarse tuffs and tuff-sandstones containing little or no lime, and apparently no organic remains. They are sedimentary tuffs of mixed composition, made up of fragments of plagioclase, rhombic and monoclinic pyroxene, brown hornblende, portions of semi-vitreous basic andesite, and palagonitic debris. In the lower levels they are fine textured with a grain of .2 to .3 mm. In the higher part their grain is .5 to 1 mm., and they are more basic in character and come near to the palagonite-tuffs. At an elevation of 200 feet they form inland cliffs, 50 feet high, in which are imbedded blocks, 2 feet across, of a blackish pyroxene-andesite with a specific gravity of 2.73, and belonging to the prismatic sub-order of the orthophyric order of the hypersthene-augite andesites. It is remarkable for the pyroxene prisms of the groundmass, and shows a little interstitial glass. These cliffs are well displayed behind Navelatha, about half a mile from Tathelevu. Between this locality and the Salt Lake

Passage, elevated reef-limestones, forming low cliffs 6 to 8 feet high, together with occasional tuff-agglomerates, occur at the coast.

THE LEA SUB-DISTRICT.—This region, which includes the mountain-range of Ngalau-levu at the back of Lea, is limited by Fawn Harbour and Vunilangi Inlet on the south coast, and by the Ndreke-ni-Wai River and a point between Viene and Lea on the north coast. Its structure, as is shown below, is very complicated, acid and basic rocks being associated in a remarkable manner; whilst over all lie the submarine tuffs. Marine and sub-aerial denuding agencies have shaped and re-shaped the surface to such a degree that it is now impossible to restore it in imagination.

On the north coast of this sub-district, about two miles east of Viene, is exposed an altered darkish porphyrite displaying large opaque crystals of plagioclase, 5 to 7 mm. long, the rock-mass being penetrated by fine veins of chalcedonic quartz, which also traverse the phenocrysts. Its specific gravity is 2·6; but on account of the imperfect development of the felspar-lathes and the amount of altered glass in the groundmass, which also contains a little calcite, it can be only generally referred to the augite-andesites. A greenish altered foraminiferous tuff showing fine cracks filled with chalcedony composes a spur in this locality. A propylitic or highly altered dolerite is exposed half-way between Viene and Lea.

As one nears Lea from the west the lofty spurs of the mountain of Ngalau-levu reach the coast, and basic tuffs and agglomerates prevail. The blocks in the agglomerate are composed of a vesicular semi-vitreous hypersthene-augite andesite, which is assigned to the second prismatic sub-order, since it carries prismatic pyroxene in the groundmass. The town of Lea is picturesquely situated on the coast at the foot of the steep mountain-slopes, being closed in on the east and west by elevated spurs descending to the sea. Fragments of jasper and chalcedony occur in the beds of the streams that here drain the precipitous sides of the range. Two dykes of dark basic rocks protrude through the beach in Lea Bay. They are composed of augite-andesites referred to genus 13 of the augite-class; but the two rocks belong to different species of that genus. In the one the felspar-lathes are only 0·04 mm. in length, and there is a little altered glass in the groundmass, the specific gravity being 2·63. In the other the felspar-lathes average 0·2 mm. in length, and the rock has a coarser texture, whilst the specific gravity is 2·7. The augite granules are large (0·03 mm.), and there

are irregular lacunar spaces filled with calcite and lined by a brown palagonite-like material.

I ascended the second highest peak of the Ngalau-levu mountain, which rises to a height of 1,680 feet behind the town of Lea, the highest summit lying to the eastward. Ngalau-lailai, which I also ascended, is a lesser peak, 1,400 feet in height, situated yet nearer to the town. Basic tuffs and agglomerates similar to those exposed in the western spur of the bay occurred all the way up to the bare rocky pinnacles forming the summits. The blocks in the agglomerates are made up of a semi-vitreous augite-andesite, which is sometimes scoriaceous or amygdaloidal, and at other times pseudo-vesicular. Augite crystals, 5 or 6 millimetres in length, are inclosed in the tuffs which contain palagonitised materials, but apparently no organic remains.

In the spur on the east side of Lea Bay occurs a light-coloured altered hornblende andesite. The brown hornblende is mostly represented by black pseudomorphs. Such a rock appears in strange contrast with its basic surroundings. This is followed, as one proceeds eastward along the coast, by basic tuffs and agglomerates. It should have been before observed that blocks of a blackish-brown olivine basalt (sp. gr. 2·89), referred to genus 13 of the olivine class, occur at intervals on the coast between Viene and Ndreke; but the rock never presented itself in position. The tiny felspar-lathes (·03 mm. long) are in flow arrangement; but there is little or no residual glass, and the augite granules (·01 mm.) occur in great abundance.

About two-thirds of the way between Lea and Ndreke-ni-wai there lie close to the shore two islets, 20 to 25 feet high, of reef-limestone, in which massive corals may be observed in their position of growth. Further east, about half a mile west of Ndreke-ni-wai, there is exposed at the coast a bedded light-coloured non-calcareous compacted tuff-rock, dipping 12° to 15° to the southward. It contains pebbles and blocks of acid and basic andesitic rocks, and may be described as an altered hornblende-andesite tuff. Basic agglomerates occur as one approaches Ndreke-ni-wai. This town lies at the mouth of the river of that name, the first river that one meets on the north side of this peninsula. There exist here between the tide-marks some hot springs, to which reference is made on page 34.

When crossing the Natewa peninsula from Ndreke-ni-wai to the head of Fawn Harbour, one reaches a height of 660 feet above the sea. This ridge represents the "divide" between the

Lea and Waikawa mountain-ranges. In the lower part of the northern slopes of this ridge occur basic tuffs and agglomerates; but between 200 and 400 feet a light-coloured acid rock of the hornblende-andesite type prevails, both in the form of agglomerate and of loose blocks. This rock is described under the second order of the hornblende-hypersthene andesites on page 299.

Descending the south slope, I found at an elevation of 500 feet a single large mass, about 4 feet across, of quite another type of volcanic rock, which is referred to the orthophyric order of the hypersthene-augite andesites (page 290). It is a dark grey almost holo-crystalline rock (sp. gr. 2·69) showing porphyritic pyroxene to the eye and displaying in its relatively scanty groundmass short stout feldspars, .05 mm. in length. On the surface of the lower two-thirds of this southern slope occur basic tuffs and agglomerates, basaltic blocks being found in the streams. The tuffs are palagonitic and contain a few calcareous particles. They apparently contain some foraminiferous shells and are doubtless of submarine origin.

It would seem that the axis or deeper portion of this ridge is composed of the hornblende and hypersthene-augite andesites, whilst the basic tuffs and agglomerates form the slopes.

With reference to the south side of the Lea sub-district, it may be observed that whilst on the north side the mountains rise up close to the sea-border, here they are separated from the coast by a broad tract of lowland, where bedded pteropod and foraminiferous clay-rocks are exposed, dipping gently to the south-east. Usually between Fawn Harbour and Vunilangi Inlet the coast is margined by low cliffs of coral-limestone, showing the massive corals in position; but sometimes the deposits above noticed compose the low cliffs and even the islets close by.

THE WAIKAWA MOUNTAINS.—This range occupies nearly the whole area of the broad and elevated promontory that is only separated from Taviuni by the narrow straits of Somo-somo, which, however, have a minimum depth of 120 fathoms. These mountains extend to the vicinity of Mbutha Bay on one side and to near Fawn Harbour on the other. Several of the peaks reach to over 1,000 feet, the greatest height given in the Admiralty chart being 1,540 feet. The whole region has a very rugged aspect, the mountains rising up near the coast, whilst the surface is much cut up into ridges and valleys.

A single traverse across the range was alone made, but the results obtained are very suggestive and may doubtless be applied

to much of this rugged promontory. I crossed the mountains from Loa to Waikawa. The summit was about a mile broad and undulating, the level varying between 900 and 1,150 feet. At one place on the top there was a deep hollow, some 300 or 400 yards across, perhaps the remains of an old crater-cavity ; but the higher slopes were so densely wooded that it was not possible to get a clear view of my surroundings. Basic tuffs and agglomerates prevailed on either side from the foot to the top of the range. Specimens obtained from between 800 and 900 feet above the sea are characteristic palagonitic tuffs of varying degrees of coarseness containing 5 to 10 per cent. of carbonate of lime and a few tests of foraminifera. At 1,100 feet I obtained a specimen which on account of the large proportion of carbonate of lime (35 per cent.) and the abundance of foraminiferal tests may be termed an impure foraminiferal limestone belonging to the group of these rocks described on page 319. The tests range up to a millimetre in size, and there are also inclosed a few large fragments, 1 to 2 centimetres in size, of shells and crystalline limestone. The residue is made of the detritus of semi-vitreous basic rocks, palagonitic debris, fine clayey material and minerals (15 per cent.), the last including beside plagioclase abundant more or less perfect pyroxene prisms, mostly of the rhombic type.

Near the summit there occurred in one place blocks of a highly basic blackish olivine-basalt (sp. gr. 2.99), marking evidently the situation of a dyke. This rock is referred to genus 13 of the olivine-class. It displays abundant phenocrysts of olivine and augite with but little plagioclase. Interstitial glass is scanty, the groundmass consisting of stoutish felspar-lathes (.06 mm. long), abundant augite granules and prisms, and magnetite.

The Waikawa mountains would thus seem to possess the same general structure that characterises many of the ranges of the island. Submarine basic tuffs and agglomerates cover their sides and their summits, the deeper rocks forming the axis of the range being in this case not so frequently exposed.

On the coast between Waikawa and Navuni, rather over a mile east of Fawn Harbour, basic agglomerates, palagonitic tuff-sandstones, and calcareous clay-rocks containing pteropod and foraminiferous tests, prevail. The tuff-sandstones and clay-rocks are bedded, the stratification being often well shown in the horizontal sections displayed in the shore-flat. In one locality within an area a few hundred yards across, a quaquaversal dip was exhibited. At Navuni, where the hills reach the coast, the

same formations occur. I ascended the stream-course there for about a mile, basic tuffs and agglomerates being exposed in its sides, whilst blocks of a heavy dark olivine-basalt¹ lay in the bed. The hot springs which issue inland at the side of this stream are described on page 35.

THE BASIN OF THE NDREKE-NI-WAI RIVER.—With the region, which is bounded on the north by the Mount Freeland Range or the Ngala mountains and on the south by the Waikawa Range, I have but slight acquaintance, except in the case of the coast fronting Natewa Bay. A little way up the course of the river Ndreke-ni-wai, which drains this area, lies the town of Koroni-yasatha, where Mr. Horne, the botanist, spent some days in 1878. Probably much of this area is not over 200 feet above the sea, and apparently there is a good deal of talasinga country.

THE COAST BETWEEN THE MOUTH OF THE NDREKE-NI-WAI RIVER AND THE FOOT OF THE NGALA OR MOUNT FREELAND RANGE.—Between this estuary and Valavala, two miles to the eastward, occurs a bedded calcareous palagonitic tuff of sedimentary origin, dipping steeply to the north. In one locality there is a rudely columnar dyke of a porphyritic augite-andesite. Coarse basic tuffs exposed in the cliffs and shore-flat of Ko-nandi-nandi Point on the side of Valavala Bay display a spheroidal structure, due probably to the vicinity of some igneous intrusion. The sea-border extending from this bay to Natewa, and farther on to Waikatakata, near the foot of the Ngala mountains, is in most parts a broad low strip of coast-land, where rock-exposures are infrequent. A dark grey andesite forms the blocks of the agglomerate in this locality. It is noticeable on account of the prismatic pyroxene of the groundmass; and it is assigned to genus 5 of the second (prismatic) sub-order of the hypersthene-augite andesites. A blackish semi-vitreous pyroxene-andesite occurs in the vicinity of Natewa.

At Waikatakata (the Fijian word for "hot water"), where an outlying spur of the Mount Freeland or Ngala Range reaches the coast, hot springs issue on the hill-side, as described on page 34. On the slopes around the springs lie huge masses of an aphanitic

¹ It displays an abundance of small phenocrysts of plagioclase, augite, and olivine partly serpentinised, in a groundmass composed in the main of coarse augite grains (.025 mm. in size) and of felspar microliths (.07 mm. in length) in smaller proportion, with little if any residual glass. Specific gravity 2.98. It is near the Waikawa basalt, referred to on p. 202, and is placed in the same genus (13) of the olivine class.

basaltic andesite having a specific gravity of 2·81 and referred to genus 16 of the augite sub-class. It displays a characteristic andesitic groundmass, showing crowded felspar-lathes in flow-arrangement with average length of ·17 mm., and containing scarcely any residual glass.

Proceeding along the coast east of Waikatakata, one enters the region of altered pyroxene-andesites, for which Mount Freeland, or the Ngala Range, is remarkable. There are first to be observed on the shore blocks of a grey altered ophitic dolerite, which belongs to the non-porphyrific division of genus 10 of the augite-andesites and is described in detail on page 275. Afterwards the characteristic rocks of the district occur. The lofty spurs of the Ngala Range here reach the shore; and between them lies the coast village of Ngara-vutu, from which the ascent to the summit is best made.

MOUNT FREELAND OR THE NGALA RANGE

This high range forms a conspicuous object in the profile of this part of the island. It derives its Fijian name from the old war-town of Ngala that was situated at an elevation of 1,500 or 1,600 feet overlooking Ngara-vutu on the west. The main mass of the range takes a crescentic sweep, 3 or 4 miles in extent and facing Natewa Bay. It incloses the coast district of Tunuloa. The steep mountain-slopes here rise to 2,000 feet and over, the greatest elevation being 2,740 feet. The densely wooded spurs of the range occupy most of the area between the town of Natewa, Kumbulau Point, and Mbutha Bay.

The summit is a long narrow ridge covered with a dense entangled mass of Freycinetia stems which render progress very difficult. The rocks exposed all the way up from the stream-courses in the vicinity of Ngara-vutu to the top, are almost all of the same type, namely altered augite-andesites. They are dark grey in colour and effervesce slightly with an acid, whilst occasionally they show a little pyrites.¹ Agglomerates were not observed and tuffs only in one locality, 1,200 feet above the sea, where a highly altered tuff composed of debris of the prevailing rocks was exposed. At an elevation of 500 feet there occurred a grey doleritic porphyritic rock, displaying large opaque crystals of plagioclase, and looking like a porphyrite. It exhibits a semi-ophitic groundmass,

¹ They are described on p. 269 under the non-porphyrific sub-genus of genus 2 of the augite-andesites.

and is probably an intrusive mass. A description of it will be found under genus 10 of the augite-andesites (page 274).

The general petrological characters of the principal summit of Mount Ngala point to its high antiquity as a volcanic mountain. It probably ranks among the oldest extinct volcanic vents in the island.

Proceeding along the coast from Ngara-vutu to Navetau, the Buli's town of the Tunuloa district, one observes blocks of basic rocks. Farther to the eastward for a distance of two or three miles basic agglomerates and basic tuff-agglomerates prevail along the sea-border, being often extensively exposed in the cliff-faces of the hills. The rock composing the blocks is a hemi-crystalline pyroxene-andesite remarkable for the prismatic pyroxene in the ground-mass, and referred to genus 17 of the hypersthene-augite sub-class.

I crossed the range to Ndevo on the other side of the peninsula from a place three or four miles west of Kumbulau Point, rising on the way to a height of 930 feet. For the lower 300 feet on the north slope basic agglomerates and basic tuff-agglomerates are exposed. They are made up of the same materials as those above described on the coast. Near and at the summit occur compacted brecciated tuffs made up of palagonitised basic materials but containing no lime, and these are associated with light greenish fine-textured hard tuffs of an acid character, but without lime or organic remains. In this last case the deposit is formed of mineral fragments (oligoclase, rhombic and monoclinic pyroxene, &c.), the debris of a hemi-crystalline volcanic rock, and a quantity of greenish alteration products.

On the south side in the vicinity of Ndevo the sea-border is composed of calcareous palagonitic clays and tuffs containing pteropod shells and large tests of foraminifera in abundance. These deposits, which are horizontally bedded, extend a mile inland and reach to between 250 and 300 feet up the slopes. A hot spring is stated to occur between the tide-marks near Ndevo.

At intervals all along the coast between Ndevo and Nuku-ndamu, passing on the way the villages of Koro-i-vonu, Tuvumila and Kanakana, fine and coarse basic tuffs, often calcareous, are to be seen exposed in the sea-cliffs and in the low hills behind. They are bedded and dip 5° to 10° W.S.W. near Ndevo and 15° to 20° S. b W. south of Kanakana. The lower slopes of the Ngala mountains here approach the coast, and it is highly probable that the submarine tuffs which form the sea-border extend a considerable distance inland and to some height above the sea. Between Nuku-ndamu

and Tukavesi, where the mountains rise close to the beach, occur basic agglomerates and agglomerate-tuffs, derived from basaltic andesites. A specimen of the last named represents an uncommon type of basaltic rock (sp. gr. 2·85), which on account of the character of the felspars and of the pyroxene of the groundmass is referred to the prismatic sub-order of the orthophyric order of the hypersthene-augite andesites (page 290).

It may be inferred from the foregoing remarks that whilst the main elevated mass of the Ngala Range is composed of altered basic andesites, the product of ancient eruptions, the basic agglomerates, tuffs, and clays, which occur on the lower slopes and in the outlying spurs, are of later date. These tuffs and clays are evidently of submarine origin, at least in the lower levels; but although fossiliferous deposits were not observed at greater elevations than 300 feet above the sea, it is probable that future investigators will find them at much higher levels. Their discovery, as before noticed, at an elevation of 1,100 feet in the adjacent Waikawa mountains, renders it likely that as in the case of the mountainous districts of the main portion of the island the whole of the Natewa peninsula was at one time submerged, or at least all the region excepting the summit of Mount Ngala.

CHAPTER XV

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE NORTH-EAST PORTION OF THE ISLAND

THIS large area, which extends for a distance of nearly forty miles from the eastern slopes of the Mount Thurston Range to Undu Point, forms the region closing in Natewa Bay on the north. It would be difficult to imagine an area of this size with a greater variety of surface or showing such a lack of arrangement of its principal features. The hills and mountains on the north side gather at the coast, and extensive inland plains, raised but a few feet above the sea and strewn with silicified corals, occupy a portion of its interior. A long valley with a very small gradient extends nearly across its breadth; and the rivers are for the most part tidal estuaries fed, except in one or two cases, by insignificant streams. There is, however, a lofty range of ridge-mountains in its broadest part attaining a height of 2,500 feet; whilst away to the east stretches the great Undu Promontory singular for the straightness of its form.

Volcanic rocks of acid types, such as oligoclase-trachytes, quartz-porphyrries, and white pumice-tuffs prevail in the northern part between Undu Point and the promontory opposite Mali Island. In the southern part, from the foot of Mount Thurston and Vuinandi to the vicinity of Tawaki, massive rocks and tuffs and agglomerates of basic characters predominate. Although my acquaintance with this area is incomplete, the data below given will be sufficient to enable a general idea to be formed of its structure. The more conspicuous features in its geology will gradually come into prominence as the various localities visited are described.

THE SOUTHERN SEA-BORDER BETWEEN VUINANDI AND THE VICINITY OF TAWAKI

The basic rocks, which characterise this long extent of coast, give place about two miles west of Tawaki to the acid rocks. I will proceed methodically with the description from Vuinandi eastward.

(a) *The coast between Vuinandi and Nakarambo.*—Along this coast, spurs from the Mount Thurston Range reach the borders of Natewa Bay, forming a succession of small bays a mile or so across, on the shores of which are situated the villages and towns of Vuinandi, Ndaku-ndaku, Korotasere, and Nakarambo. The basaltic rocks characteristic of the vicinity of Vuinandi are predominant here; but agglomerates and tuffs are of rare occurrence, the prevailing rocks exposed in the spurs being fine textured basaltic andesites (sp. gr. 2·82). A calcareous tuff-clay is, however, to be observed in the east point of Vuinandi Bay, where it is apparently penetrated by a dyke of the above mentioned rock. In Ndaku-ndaku Bay there issue from the shore-flat between the tide-marks some hot springs which are referred to on page 34.

(b) *The coast between Nakarambo and Waimotu.*—In this tract we meet with rocks of a somewhat different character, though still basic in their type. Through the agglomerates and agglomerate-tuffs of the spurs protrude coarsely crystalline grey pyroxene-andesites.¹ They are to some degree altered, and are characterised by their abundant phenocrysts of plagioclase and of rhombic and monoclinic pyroxene, the groundmass being relatively scanty. The agglomerates are formed of similar materials. There is an interesting exposure in the point east of Nakarambo. My specimens from this locality were unfortunately lost; but in my notes reference is made to the coarsely crystalline grey andesite above noticed, to the later intrusion of a dark amygdaloidal rock, and to an altered calcareous tuff.

(c) *The coast between Waimotu and Natasa Bay.*—A low belt of land often forms the sea-border. Between these two localities there is a broad estuary, the village of Vanuavou being situated on the right side and Malati on the left side. Tuffs usually calcareous

¹ These rocks are in most cases referred to the orthophyric and felsitic orders of the hypersthene-augite andesites. The rocks of the last-named order prevail, and form the type of the group, as described on p. 291.

and probably submarine are here displayed together with basaltic andesites.

(d) *The coast between Natasa Bay and the vicinity of Tawaki.*—This extensive stretch of sea-border, nearly 15 miles in length, is characterised by hilly spurs and long intervening low-lying tracts. The prevailing rocks exposed are tuff-clays, somewhat hard and altered, and coarser basic tuffs sometimes calcareous and overlying the former. These sedimentary deposits, which are evidently submarine, are often bedded and have a fairly constant dip over most of this region of 10 to 15 degrees to N.W. or W.N.W. They are frequently pierced by dykes, 6 to 10 feet thick, of compact basic rocks. A specimen of one of these dyke-rocks from between Natasa and Vatu-karoa is a doleritic basalt with scanty olivine (sp. gr. 2·81)¹; but the rock of the dykes east of Vatu-karoa is less basic (sp. gr. 2·72), and may be described as an augite-andesite² with a doleritic structure in part disguised by alteration. Between Natasa and Sangani there is a remarkable exposure of an intrusive opaque white rhyolitic rock associated with altered tuffs. This rock, which has undergone some degree of alteration, is described on page 311. It is the only indication of the vicinity of a region of acid rocks that I came upon on this tract of coast. It probably, if traced inland, would be found connected with the district of acid rocks. In following along the coast, however, towards Undu Point, the region of acid rocks is not reached until within 2 or 3 miles west of Tawaki. Reference should be made here to two hot springs that, as described on page 33, rise up on the coast at Natuvu, a little east of Lakemba.

THE INLAND MOUNTAINOUS REGION BETWEEN THE EASTERN FOOT OF THE MOUNT THURSTON RANGE AND THE VICINITY OF TAWAKI

This inland region corresponds for the most part to the tract of coast before described between Vuinandi and the vicinity of Tawaki. We have here a very much broken area traversed in a northerly and southerly direction by mountain-ridges and penetrated in places on the north side by prolongations of the Wainikoro and Kalikoso plains. The two loftiest summits, the Ndoendam and

¹ It belongs to genus 37 of the olivine class. The felspar-lathes average 0·2 mm. in length, and there is a little altered interstitial glass.

² It is referred to genus 16, species D, of the augite-andesites. The felspar-lathes have an average length of '3 mm.

Savu-riti peaks of the chart, rise respectively to heights of 2,481 and 2,238 feet. The former is the Hale Peak of the Wilkes' Expedition; but as regards the native names there is some confusion and I have not been able to clear it up. Several of the lesser peaks rise to over a 1,000 feet, and four or five of them to rather over 1,500 feet.

With the exception of the fixing of the positions of the more conspicuous peaks, the interior of this part of the island is unsurveyed. I was able to lay down my positions approximately; but before a systematic examination can be made of the geology of this region a survey is necessary. Several traverses and ascents were made by me; but much more in the way of exploration remains to be done. I venture, however, to think that from the data below given a fairly accurate notion of some of the leading geological features of this region may be formed. The districts visited will be described in their order from east to west.

(a) *The mountainous district east of the mountains of Vungalei and Nailotha, extending to the vicinity of Tawaki.*—Mr. Thomson¹ in his map of the sea-border of this district shows a continuous coast range from near Tawaki to Natasa lying about two miles inland. This is the appearance when the region is seen in profile from a distance; but when viewed from an elevation in its interior its surface is seen to be for the most part traversed by a series of mountainous and hilly ridges trending roughly north and south, the greatest height not exceeding 1,500 or 1,600 feet.

The geological character of the sea-border of this district has already been described on page 208. It is there shown that fine and coarse sedimentary tuffs, sometimes calcareous, and often penetrated by basic dykes, here prevail. Their general story is one of great denudation, and we have the same testimony impressed on us when examining one of the inland mountain-ridges.

I followed the crest of one of these ridges from the hamlet of Nawi, on the headwaters of the Vui-na-savu River, in a southeasterly direction for about 4 miles to the peak of Uthulanga, which overlooks Lakemba on the shore of Natewa Bay. During the walk my level rose fairly gradually from that of Nawi, less than 100 feet above the sea, until near Lakemba, where a height of 1,400 feet was attained. Here the ridge abruptly terminates in the round-topped peak of Uthulanga, which rises steeply from

¹ *Proceedings*, Queensland Branch, Geographical Society of Australia, vol. i.; 1886.

its crest for another 150 feet or rather more, and has a precipitous face on the southern side descending far down the mountain-slope. This peak, which is about 1,550 feet above the sea, when seen from the opposite shores of Natewa Bay is very conspicuous and looks like a thumb or a nose. The first part of the Fijian name of this peak signifies a nose.

The hamlet of Nawi, from whence the ridge begins, is built on a low mound-like "rise," which is composed of a dark-grey hypersthene-gabbro. Since plutonic rocks are of very rare occurrence in this island, the Nawi gabbro has a particular interest. It belongs to the group of plutonic rocks described on page 250; and is to be referred to the more basic kinds, its specific gravity being 2·84. In appearance it is like a diallage-gabbro, and in the slide displays monoclinic and rhombic pyroxene filling the interspaces between the large plagioclase crystals and undergoing respectively the diallage and bronzite stages of schillerisation. This rock forms the type of the group and need not be referred to in more detail here. It should be added that in the bed of the neighbouring river occur blocks of a basaltic andesite (sp. gr. 2·86) referred to genus 1 of the hypersthene-augite andesites. It is a less crystalline form of the gabbro just mentioned.

The prevailing rock exposed for the first 2 miles on the crest of the ridge (by starting from Nawi) was a greenish porphyrite displaying large opaque crystals of oligoclase, but showing much alteration of the propylitic kind, its specific gravity being 2·5, but the structure of the groundmass is much disguised. During the next mile, basic agglomerates and a massive hypersthene-augite andesite were exposed. The last-named is semi-vitreous, and on account of the prismatic pyroxene of the groundmass is placed in genus 5 of its sub-class. Its specific gravity is 2·7. In the last and fourth mile of the ridge was exposed a dark grey doleritic basalt (sp. gr. 2·85), which rings like clinkstone under the hammer, and weathers in a honeycombed fashion. The felspar-lathes average 3 mm. in length, the residual glass being scanty. The pyroxene phenocrysts include some of rhombic pyroxene; and the rock is therefore referred to genus 4 of the hypersthene-augite andesites. The actual peak of Uthulanga, as it rises abruptly about 150 feet from the end of the ridge, is of agglomerate, the blocks being composed of a compact grey andesite.

The peculiar succession of rocks displayed in this mountain-ridge along its length of four miles is worthy of notice. Neither vesicular nor scoriaceous rocks came under observation; and it is

to be assumed that there existed originally a line of submarine vents, some of them ejecting acid and others basic materials. Mainly on account of the great marine erosion during the period of emergence, but partly also on account of the subsequent sub-aerial denudation, a plain ridge now represents this line of vents. Probably the peak of Uthulanga, which is evidently an old volcanic neck, represents the last of the stages in the volcanic history of this ridge; but a very long period must have since elapsed. When, however, we look at the exposed gabbro at the other end of the ridge, we have to carry the period much farther back, since here the superjacent surface volcanic rocks have been stripped off completely. On page 2 I have referred to an island in the Solomon Group where we have such a chain of ancient vents of acid and basic rocks. In that case the forms of the separate hills indicating the original vents are still to be recognised. In this old mountain-ridge of Vanua Levu no such outlines remain except in the instance of the terminal peak.

(b) *The Nailotha and Vungalei Range*.—This lofty range, which towers above all around it, attains a height of 2,481 feet in the peak of Nailotha and of 2,238 feet in that of Ndrukau or Vungalei. The first is, as I infer, the Ndoendamu or Hale Peak of the charts; but it is uncertain whether the name Savu-riti should be applied to the northern peak of the range as it is in the charts, or whether it belongs to an independent peak farther to the east. By the natives in the vicinity the northern peak is known as Ndrukau, and I have added the name of Vungalei from the village at its foot. The southern peak is that of Nailotha. The range runs roughly north and south. It is, however, obvious that the internal topography of this part of the island is but scantily known.

Brief reference will first be made to the country bordering the range on the north-west and west sides in the vicinity of the villages of Vungalei and Tembe. In proceeding south from Kalikoso, which lies in the midst of the low-lying Wainikoro plains, to Vungalei one traverses this level district, of which the elevation is never more than 150 feet above the sea and often much less. About a mile south-east of Kalikoso the limit of the region of quartz-porphyrries and of acid tuffs is passed and the area of basic rocks is entered, a dark semi-vitreous pyroxene-andesite with a flinty fracture prevailing at the surface as far as Vungalei. This rock displays a few small phenocrysts of oligoclase and pyroxenes in a blurred glassy groundmass exhibiting

the felspar and pyroxene microliths in process of development (sp. gr. 2.46).

Vungalei itself is only elevated about 130 feet above the sea. In proceeding from this village to Tembe, lying about two miles S.S.W., one crosses a line of hills, about 600 feet in height, which form a spur of the main range. Basic agglomerates similar to those found on the slopes of Mount Vungalei, as described below, prevail in the district between these two villages up to the top of the intervening hills. In places one notices that they overlie the ordinary sedimentary deposit, known as "soapstone," a slightly calcareous clay-tuff but showing no organic remains to the eye. The rock exposed in the stream-courses is a semi-ophitic basaltic andesite (sp. gr. 2.74) which contains a considerable amount of interstitial glass.¹ When proceeding S.S.W. from Tembe on the way to Nandongo one passes on either hand, as described on page 216, hills about 700 feet high displaying vertical cliffs formed of agglomerates over-lying finer sedimentary beds apparently of the "soapstone" character.

I made the ascent of Mount Vungalei from the village of that name. The peak is also known as Ndrukau. Basic agglomerates were exposed all the way up to an elevation of about 2,000 feet, where a bed of a somewhat scoriaceous basaltic andesite was displayed, the upper 200 feet being inaccessible but of the same agglomerate. At a height of 300 feet was observed another layer of the same basaltic rock. These intercalated beds appeared to be lava-flows rather than horizontal dykes. The agglomerates become less coarse in the upper part of the mountain where they take the character of agglomerate-tuffs. The blocks are composed, like those in many other parts of the island, of a dark semi-vitreous basaltic andesite, but often scoriaceous. But the most remarkable features of these agglomerates are the indications of two distinct pauses in their deposition afforded by the occurrence at elevations of 900 and 1,700 feet of a single horizontal bed, two to three feet thick, of coarse palagonite-tuffs. Each bed is exposed at the foot of a tall cliff of agglomerate forming a line of escarpment along the mountain-side. The larger fragments making up these tuffs are usually from 2 to 3 millimetres in size; but the process of palagonitisation is not complete; and we find inclosed abundant angular pieces of a dark fresh tachylyte-glass, finely vesicular, and fusing readily in the ordinary spirit-lamp flame. The tuffs contain little or no lime and seemingly no

¹ Referred to genus 9 of the augite-andesites.

organic remains. In the lowest bed I noticed a little water-worn gravel. Both beds pass gradually into the underlying agglomerate; but their upper limits are well defined and the agglomerate commences abruptly.

It is thus seen that in the formation of the agglomerates there were two pauses when they gradually gave place to deposits of fine detritus made up of a vesicular basic glass that has since been largely converted into palagonite. Then followed a sudden renewal of the agglomerate-producing process. We can scarcely doubt that the agglomerates, with their scoriaceous blocks, and the palagonite-tuffs are in the main the direct products of volcanic eruptions. The rival claim of marine denudation as the agency concerned can be mostly but not altogether excluded. The agglomerates and tuffs of Mount Vungalei cannot be distinguished from those so often described in the case of the great inland ranges of the other parts of the island, the submarine origin of which is frequently demonstrated by the inclosed organic remains. It would seem that in the instance of Vungalei these deposits took place around the shores of a volcanic mountain that rose above the sea. On page 315 it is pointed out that in Stromboli with its dribbling eruptions we have a good illustration of the manner in which such deposits could be formed.

My examination of the mountain of Nailotha was restricted to the lower slopes up to an elevation of 600 feet; but the results obtained are very suggestive. When following up the stream-course on the way from Tembe to the mountain one notices in its bed blocks of a light-coloured rock like a compact quartzite. It is, however, a highly altered oligoclase-trachyte (sp. gr. 2.53) with its structure much disguised by secondary quartz. This is the first intimation one gets, on leaving behind the district of basic agglomerates about Tembe, of the otherwise unexpected character of the acid rocks displayed in the lower part of Nailotha.¹

A torrent here cuts deeply into the mountain-side. At the base, between 200 and 300 feet above the sea, a bluish-grey rather scoriaceous rock with the steam-pores drawn out to a length of from 1 to 2 centimetres, is first exposed. Its specific gravity after allowing for the cavities is less than 2.6. It shows a groundmass partly disguised by secondary quartz and containing numerous small vesicles lined by quartz and filled with viridite and epidote. Where the alteration is less advanced small parallel

¹ The general characters of these rocks are described on p. 308.

felspar-lathes with fine decomposing pyroxenes are shown. The lathes give extinctions of two or three degrees and average .04 mm. in length. In its somewhat scoriaceous nature, in the absence of phenocrysts, and in its less altered condition, this rock differs from those exposed higher up the ravine; but it is evidently to be referred to the same acid type. At a height of 300 feet a light grey highly altered oligoclase-trachyte (sp. gr. 2.43) is exhibited. It contained originally some phenocrysts of felspar and pyroxene, which, however, have been more or less replaced by calcite, quartz, and other materials; whilst the groundmass, originally hemi-crystalline but now blurred by the deposition of silica, shows felspar-lathes in process of development.

A little farther up the gorge there is displayed another highly altered rock with a siliceous appearance, such as has been noticed above as forming blocks in the stream near the foot of the mountain. It is an oligoclase-trachyte impregnated with crystalline silica and exhibiting a singular prismatic structure, the small columns or prisms being only 3 or 4 inches in diameter. Between 400 and 500 feet occurs a light-coloured compact rock sparkling with pyrites and also displaying a columnar structure, the columns being between 4 and 6 inches across. It looks like a limestone and effervesces freely with an acid; but it is in fact a highly altered oligoclase-trachyte (sp. gr. 2.5) of the propylite type. It seems originally to have inclosed a few phenocrysts of oligoclase, sanidine, and pyroxene, and here and there a stout felspar-lathe is to be noticed in the groundmass giving straight extinction. The whole texture of the rock, however, is more or less impregnated with secondary quartz, calcite, chlorite, viridite, pyrites, &c. Farther up the ravine, between 500 and 600 feet in elevation, is displayed a remarkable quartz-porphyry which exhibits opaque porphyritic crystals of felspar as well as rounded crystals of quartz in a grey compact base. It has been subjected to considerable alteration and will be found described on page 310.

At 600 feet large slabs of the ordinary sedimentary clay-tuffs, containing but little lime and showing no organic remains to the eye, lay about on the more level slopes, and evidently formed a surface deposit incrusting the altered massive rocks. If my ascent had lain up the mountain-side away from the stream-courses, these sedimentary rocks would alone have been observed. In the gorge, however, is exposed to view the deeper-seated rocks that make up the mountain's mass. We have here a thickness of about 400 feet of altered acid rocks. All are doubtless intrusive, and were sub-

jected to alteration after the development of the columnar structure and before the deposition of the overlying clay-tuffs or "soapstones," which are no doubt of submarine origin. These sedimentary tuffs belong probably to the period when the submarine agglomerates and palagonite-tuffs of the neighbouring peak of Vungalei were formed.

(c) *Traverse of the coast range from Nandongo to Vanuavou on the shore of Natewa Bay.*—This route was taken by Mr Horne, the botanist, in 1878. I approached Nandongo from Tembe to the northward. The road at first lay between hills about 700 feet in height displaying in their precipitous faces agglomerates overlying fine sedimentary tuffs. These deposits in the form of slightly calcareous basic tuff-clays, the so-called "soapstones," are exposed in the bed of the Wainikoro River as one nears Nandongo. This village, which is situated on the headwaters of the Wainikoro at an elevation of about 180 feet above the sea, lies near the foot of the range. In its vicinity there is a small thermal spring which is referred to on page 33.

Proceeding south from Nandongo one notices in the stream-course at the foot of the slopes the sedimentary tuff deposits above mentioned, bedding and dipping gently to the west. Farther up the slopes, higher than 250 feet above the sea, there are exposed the deeper-seated rocks of the range in the shape of compact reddish rocks (sp. gr. 2.48), which appear under the microscope to be highly altered acid andesites or oligoclase-trachytes originally displaying flow-structure and a fair amount of glass, but now much disguised by the formation of secondary quartz. On this north slope of the range I also found an amygdaloidal variety of the same altered rocks containing irregular amygdules, 5 or 6 millimetres long, of fibrous quartz or chalcedony. Blocks of basaltic andesite were observed on the summit, which has an elevation of 950 to 1,000 feet. On the southern slopes descending towards Natewa Bay coarse basic tuffs together with blocks of basaltic andesite are chiefly exposed. The last-named probably represent dykes both on the south slope and on the summit. The rocks exhibited on the portion of the coast of Natewa Bay corresponding to this range are dark and light-coloured sedimentary tuffs usually calcareous, with occasional basaltic andesites indicating dykes. . . . From this traverse it would appear that the range has an axis of altered acid rocks overlain by basic sedimentary tuffs and pierced by basaltic dykes.

(d) *The mountainous district lying between the head waters*

of the Wainikoro River and the Mount Thurston Range.—Of this region I know very little. The highest peak according to the chart has an elevation of about 1,600 feet. Some indication of the character of the inland rocks may be obtained from that of those exposed on the coast between Nakarambo and Waimotu where, as observed on page 208, grey pyroxene-andesites, coarse in texture and almost holo-crystalline in structure, protrude through agglomerates of the same materials. When on the way from Ngelemumu to Wainikoro I crossed the extreme northern prolongation of this range where the elevation above the sea is only 700 feet. Non-calcareous basic tuff-clays occur on the slopes ; but the deeper-seated rocks, judging from an exposure on the east side, are dark grey altered pyroxene-andesites penetrated by fine cracks filled with a mosaic of quartz and having a specific gravity of 2.7. On the summit I found a gritty sandstone-like rock, of which my specimen has been lost. In a stream at the foot of the east slope occur small blocks of basaltic andesite probably derived from a dyke. The region of acid rocks, such as quartz-porphyrries, oligoclase-trachytes, &c., is not entered until about two miles south-west of Wainikoro.

THE COAST RANGES AND SEA-BORDER BETWEEN MBUTHAISAU AND THAWARO OR MBEKANA BAY

We have in this region the mountains and hills at the coast and the low-lying plains inland. This feature of the north side of Vanua Levu is very remarkable. For some sixty miles, that is to say, for more than half the length of the island, between the mouth of the river Ndreketi and Thawaro or Mbekana Bay, Vanua Levu possesses this character. The coast ranges west of Lambasa, where basic rocks evidently prevail, have been referred to on pages 135, 136. Those east of the Lambasa mountains as far as Thawaro Bay will be dealt with here ; and instead of basic we find acid rocks, such as quartz-porphyrries akin to the rhyolites, oligoclase-trachytes, pumice-tuffs, &c.

The sea-border is here characterised not by a continuous range running parallel to the coast, as in the case of the district between Nanduri and the Ndreketi River, but by a number of separate groups of hills and lesser mountains, separated by deep gaps or valleys which are occupied by tidal rivers and extensive mangrove swamps. The tide ascends these rivers into the plains behind the coast ranges, so that a depression of only 30 feet would convert

these groups of hills into separate islands and would cover much of the inland plains with the sea. The hills attain an elevation of 1,200 or 1,300 feet a mile or two inland and descend often as bold promontories to the coast. I will refer in order to the different parts of this sea-border.

(1) THE SEA-BORDER BETWEEN LAMBASA AND MBUTHAI-SAU

In the sea-border between Lambasa and Mbuthai-sau we have the junction of the regions of basic and acid rocks, the former extending westward to Naivaka, the latter reaching to Undu Point. In such a locality the two types of rocks might be expected to be associated, and this is what occurs. Acid pumice-tuffs and basic agglomerates, sometimes associated, are here displayed. In the low hills between Lambasa and Vuni-ika Bay, which lies west of Mbuthai-sau, I found basic agglomerates prevailing, together with some acid pumice-tuffs. The blocks in the agglomerates are composed of a blackish semi-vitreous pyroxene-andesite (sp.gr. 2.68), which is characterised by prismatic pyroxene in the groundmass, and is referred to genus 6 of the second sub-order of the hypsitherene-augite andesites described on page 287.

East of Vuni-ika on the way to Mbuthai-sau, at an elevation of about 50 feet above the sea, dark tuffs containing small fragments of reef-limestone are exposed in a cutting. A little farther on there is a considerable deposit of a pale grey rhyolitic pumice-tuff, a soft stone easily worked, and indeed now quarried by the plantation authorities. It contains no lime and in microscopical characters is scarcely distinguishable from a sample of fine pumice debris collected by me in the Chirica district of Lipari Island. It is made of fragments up to a centimetre in size, of ordinary fibrillar pumice in a matrix of much finer material of the same nature. Portions of crystals of glassy felspar (oligoclase and sanidine) also occur in it, together with some quartz and rhombic pyroxene.

The association in this locality of acid and basic eruptive products was observed by Dana in 1840 in the cliffs of "Mali Point."¹ It is not quite clear whether Mali Island, which lies immediately adjacent to the coast, is here alluded to, or whether it is a headland opposite to it. Dana describes the deposits displayed in these cliffs as coarse aggregates of fragments of pumice and decomposing trachyte, which pass on the one side into fine

¹ *Geology of the United States Exploring Expedition.*

clayey material, and on the other into an agglomerate formed of angular blocks of vesicular and compact basalt with the interstices filled with pale yellow tufaceous material.

East of the Avuka Range that limits the Lambasa plains on this side is the picturesque valley of Mbuthai-sau. This broad valley runs in a south-east direction into the heart of the island. So small is the gradient that the river flowing down it can be ascended in boats for some miles ; whilst Ngele-mumu, a village situated between 5 and 6 miles up the valley, is not much over 50 feet above the sea. This valley in its lower part roughly divides the regions of acid and basic rocks that lie east and west of it respectively. It has, however, been above pointed out that the two regions overlap in the coast region on the west side of the valley. The two types of rocks are also associated in the coast hills immediately east of the valley, since when striking inland from Lloyd Point to the Mbuthai-sau sugar-cane district, one leaves behind the acid rocks at the coast and traverses a region of basic agglomerates. With these qualifications, therefore, the above line of demarcation holds good.

(2) THE SEA-BORDER BETWEEN THE MBUTHAI-SAU AND THE LANGA-LANGA RIVERS

The rocks predominating in this district are white and pale-yellow pumice-tuffs and pumice agglomerates, with quartz-porphyrries and oligoclase-trachytes as intrusive masses. The light colour of the sea-cliffs, thus composed, makes them conspicuous from seaward. Their appearance evidently led Mr. Horne into an error in 1878 when he viewed this coast from his canoe during his sea-passage from Lambasa to Tutu. "The coast from Lambasa"—he says—"is a series of bold projecting bluffs of agglomerate interspersed with seams of coralline sandstone."¹ The principal feature of this coast, however, is the prevalence of light-coloured pumice-tuffs, though it is not improbable that elevated reef-formations may occur in some localities.

I particularly examined the coast districts in the vicinity of the Wainikoro and Langa-Langa rivers. In a spur that descends to the right bank of the river, a little above the mouth of the Wainikoro, is exposed an open-textured rhyolite or quartz-porphyry containing, as described on page 310, phenocrysts of glassy felspar (oligoclase and sanidine), quartz, and a little hornblende. Some

¹ *A Year in Fiji*, p. 22.

interesting exposures occur on the coasts between Narikosa Point (Nari-Roso Point of the chart) and the mouth of the Wainikoro. Here the pumice-tuffs and agglomerates are pierced by dykes, some of them vertical and 6 feet across and composed of a light-grey rhyolitic rock, similar except in its compact texture to the rock above mentioned.¹ The small quartz crystals, which are 1 to 2 millimetres in size, are sometimes bipyramidal. Many of them are rounded and have a fused-like surface. The pumice-tuff, which displays no effervescence with an acid, is composed mainly of finely pulverised vacuolar and fibrillar isotropic colourless glass, and contains also small fragments of glassy felspar and small rounded quartz crystals, such as occur in the rock forming the dykes in these deposits. Imbedded in the tuffs in places are small masses, up to 4 inches in size, of a pretty grey vesicular rhyolite-glass exhibiting the intermediate condition between compact obsidian and pumice which is so characteristic of the rocks of Vulcano in the Lipari Islands. A more detailed account of this rock is given on page 311. In the pumice-agglomerates of this locality occur pale-yellow decayed and altered pumice blocks.

The headland, known as Narikosa Point, which lies between the mouths of the Wainikoro and Langa-linga rivers, terminates in a rocky spur formed by a large intrusive mass or dyke of a reddish oligoclase-trachyte altered in character and displaying in places a rudely columnar structure.² The pumice-tuffs and agglomerates are well exposed at the coast between Narikosa Point and the Langa-linga River. In the vicinity of Songombiau, a village here situated, the tuffs are penetrated by dykes. One dyke at the back of the village is 4 or 5 feet thick and has vitreous margins. It is composed of a darkish pyroxene-andesite which in the interior of the intrusion is hemi-crystalline and a little vesicular, but in the margins it is more glassy and rather scoriaceous.³ Though not a basic rock in itself, its specific gravity in the compact state being only about 2.55, it is relatively basic when contrasted with the rhyolitic and trachytic rocks of the district, which have when compact a specific gravity of not over 2.3.

Pumice-tuffs and agglomerates appear in the cliff-faces of the hills on either side of the lower course of the Langa-linga River

¹ Described on p. 310.

² These rocks are described on p. 308.

³ It contains small phenocrysts of plagioclase (medium andesine), and or augite and rhombic pyroxene, and is referred to genus 1 of the hypersthene-augite andesites.

from the vicinity of Kalikoso to the sea. At one place about 3 miles up the river a dyke of trachyte, much altered and showing columns 12 to 18 inches across, was exposed at the bank.

(3) SEA-BORDER BETWEEN THE LANGA-LANGA RIVER AND THAWARO BAY

The next part of the coast which I visited was that opposite Tutu Island. Here a range of high hills, 1,100 or 1,200 feet in height, sends a lofty spur to the sea, in the precipitous faces of which are exposed breccia-tuffs and agglomerates derived from acid rocks. A specimen of the tuffs shows, besides fragments of altered rhyolitic or trachytic rocks, portions of decomposing pumice, the vacuoles and tubular cavities of which are filled with alteration products. The blocks in the agglomerates are altered oligoclase-trachytes, both compact and vesicular. These deposits are non-calcareous and rarely display bedding; but in one place there was a rude arrangement of the materials, the dip being to the north-west. I crossed this coast range where it is only 600 feet above the sea, and descended into the Kalikoso plains in the vicinity of Numbu.

In the coast district between Tutu Island and the village of Naua, $3\frac{1}{2}$ miles to the east, the same altered coarse pumiceous and trachytic tuffs, occasionally bedded and dipping W.N.W., form the low hills near the sea. In one place, where the elevation was less than 200 feet, I noticed on the surface small fragments of branching corals. They had perhaps weathered out of the tuffs, and though in part silicified still effervesced freely in an acid.

Between Naua and the town of Visongo occur low hills formed of acid tuffs. At an elevation of 200 feet the tuffs display a remarkable character. When examined with the lens they are seen to be crowded with the minute tests of foraminifera of the "*Globigerina*" type. The deposit forms a fairly hard light-grey clay-rock which according to the usual acid-test has no lime. Under the microscope it is seen to be composed nearly in equal proportion of the tests of foraminifera and of very fine detritus apparently derived from acid rocks, the materials being generally not over .01 mm. in diameter, though some of the felspar fragments measure .05 mm. across. A secondary process of silicification, as exhibited in the occurrence of minutely granular quartz, has affected the matrix of the clay as well as the tests of the foraminifera. The deposit is of

deep-water origin and appears to have been formed from the fine washings of a coast some distance away.

It is noteworthy that the surface in this locality is in places strewn with quantities of angular fragments and round pebbles of chalcedonic flint, together with large nodules which when broken across are found to be occupied by radiating crystals of quartz and were doubtless formed in the cavities of some rock. Reference has already been made to the partially silicified coral fragments lying on the surface of the low coast hills a few miles to the west of this locality. They indicate a relatively recent emergence and we get the same indication from the flints on the surface of this district. These evidences, however, relate only to the last stage of the emergence. The testimony of the silicified "*Globigerina*" clay carries us back to the earlier periods of these changes of level, and probably dates back to a time when the greater part of this portion of the island was submerged, with the exception of the mountain peaks. Not the least interesting feature of the emergence is the silicifying process that accompanied it. This is illustrated on a much greater scale in the neighbouring inland plains of Kalikoso and Wainikoro which are described in Chapter XXV.

Proceeding eastward from Visongo to Namukalau one traverses a coast district not elevated more than 300 feet above the sea. Here there are displayed whitish and pale yellow compacted tuffs differing in aspect from those prevailing to the westward and often bedded, the dip being about 20° N.W. or N.N.W. They show no lime and apparently inclose no organic remains. Where the upper surface of a bed is bared, it shows regular shrinkage-lines inclosing hexagonal spaces 2 to 3 inches across; but there is no corresponding columnar structure in the bed-mass. The rock is very light in weight and homogeneous in texture and looks a little like China-clay. In a section its structure appears obscure; but it seems to be formed of the finest detritus, derived from some acid partly devitrified glass, the pumiceous structure being in places faintly indicated; but the whole mass appears to have been subjected to a process of alteration perhaps similar to the ultimate palagonitic change in basic rocks. In the slide a few small felspar fragments, about .1 mm. in size, are displayed.

Just east of Namukalau is the mouth of the Vui-na-savu River, the Na Savu River of the chart. This is a tidal river, and is navigable for boats for several miles. In the lower part of its course agglomerates and tuffs prevail, probably in part at least derived from acid rocks. Near Rauriko, which lies about 5 miles

up the river, a bare bluff, overlooking the valley on the east, is formed of a decomposed trachytic rock remarkable for the fact that it displays, as described on page 370, faint magnetic polarity. Above Vitina, a mile or two farther up, I found a similar rock but amygdaloidal in character. On the head-waters of the river is situated the hamlet of Nawi, where, as mentioned on page 211, a plutonic rock of the gabbro type occurs. Tuffs and agglomerates appear to prevail in the low coast tract between the Vui-na-Savu river and Thawaro Bay.

In drawing some general inferences respecting the acid formations, mostly fragmental in character, that are displayed in the sea-border between Lambasa and Thawaro Bay, it is necessary to distinguish between the deposits west and east of the Langa-langa River. Between Lambasa and the river just named the tuffs may usually be regarded as the products of sub-aerial eruptions. Some of the specimens might have been obtained, as far as their characters go, from the pumice-districts in the island of Lipari. Their limeless condition and the apparent absence of organic remains are noteworthy features, though of course the products of sub-aerial eruptions may be deposited under the sea. It is, however, remarkable that no compact obsidian came under my notice. The fragments of rhyolitic glass, intermediate in structure between compact obsidian and pumice, that were imbedded in the pumice-tuffs in one locality, were probably ejected from some sub-aerial vent.

In the region between the Langa-langa River and Thawaro Bay acid tuffs and agglomerates prevail; but they have all been subjected to alteration by the deposition of secondary silica, and the pumice-structure when present is largely disguised. They have evidently, in part at least, been derived from compact rhyolitic and trachytic rocks, and are probably in some measure the products of marine erosion. Although neither lime nor organic remains were detected, the presence of the altered "Globigerina" clay near Visongo is very suggestive and indicates a considerable submergence of this region at some distant period.

Much, however, remains to be done in the examination of the peaks of the coast ranges of this part of Vanua Levu; and it is likely that some interesting results will be obtained from such an exploration.

CHAPTER XVI

DESCRIPTION OF THE GEOLOGICAL AND GENERAL PHYSICAL FEATURES (*continued*)

THE NORTH-EAST PORTION OF THE ISLAND (*continued*)

THE WAINIKORO AND KALIKOSO PLAINS

THESE extensive inland plains occupy a considerable area in this part of the island. I estimate that there is an area of about 20 square miles that does not exceed an elevation of 100 feet above the sea and is often much less. Of the two villages situated in the midst of these plains, about 5 miles inland, Kalikoso is about 30 feet and Wainikoro is scarcely 20 feet above the sea ; whilst much of the surrounding district is similarly low. Taking the 300-feet contour-line as a guide, this low-lying region, as shown in the map, would be much larger. The plains are backed on the south by the high mountain-range of Vungalei and Nailotha. On the north the coast-ranges, which attain a height of 1,100 or 1,200 feet, separate them from the sea-border ; whilst on the west they are shut off from the Mbuthai-sau valley by a line of hills, of which the minimum elevation is about 700 feet. This region is occupied by the scanty open vegetation characteristic of the "talasinga" or "sun-burnt" districts. The tall "Ngasau" reed is common ; the Pandanus trees are frequent ; and amongst the bushes and small trees are represented "Dodonæa viscosa," "Morinda citrifolia," and a species of "Hibbertia."

Different rivers and streams, rising in the mountains on the south side of the plains, traverse this area ; and after breaking through the coast-ranges reach the sea. They acquire an exaggerated size from the circumstance that they are in great part tidal estuaries. The tide ascends them for several miles reaching

behind the coast-ranges into the plains; whilst the dense mangroves, which line their lower courses amongst the hills, extend beyond into the low-lying level districts farther inland. Boats can follow up the winding course of the Wainikoro River until they reach the village of that name, which lies about five and a half miles in a direct line from the coast and nearly in the centre of this part of the island. The mangroves extend up to the village. The Langa-linga River, which is of much smaller size, is similarly navigable for three or four miles. The mangroves that line its banks spread out in broad tracts when in ascending the river we emerge from the hills into the plains. Above the influence of the tide it dwindles into a stream ridiculously small. The same remarks apply to the river two miles to the eastward. The Vui-na-savu River near the eastern margin of this low-lying region can be ascended by boats into the heart of the island.

From the foregoing remarks it will be expected that some portion of this low-lying inland region will be occupied by swamps. This is in truth the case. About one and a half miles north-east from the village of Kalikoso is a small fresh-water lake, about 100 yards across, which lies in a slight depression in the plains and is surrounded by a wide margin of swampy ground, occupied by reeds and sedges, in which one sinks knee-deep when approaching the banks. The level of the surface of the lake is not over 25 feet above the sea, and only a foot or so below that of the plains around. Since the depth, as I ascertained it, is 15 to 18 feet, it follows that the bottom of the lake is only a few feet above the high-tide level. The mangroves extend to within a mile of its border; and it is possible that though lying about five miles inland, it may be indirectly affected by unusually high tides. It would be interesting to determine whether the water is ever brackish.

This small lake is, or was, regarded with superstitious awe by the natives on account of the floating islands that it contains. Different legends are connected with it, and the Fijians have given it the name of "Vaka-lalatha," in allusion to the drifting of the islands from one side of the lake to the other, the small trees growing upon them acting "in the manner of sails." Mr. Horne, who was in this locality in 1878, refers to the lake in his book, *A Year in Fiji* (p. 24); but does not appear to have seen it. Mr. Thomson¹ visited it in 1880, and describes it as containing a single floating island, a quarter to a half an acre in extent. The

¹ See paper quoted on p. 31. It is noteworthy that Mr. Horne refers only to a single floating island.

island was in existence, the natives said, in the days of their great-grandfathers, a statement indicating that the people of the district had no reason to doubt its antiquity. A chief, who formed one of the party, dived under the island.

When I visited this lake in 1899 there were three floating islands, named by the natives "Wanga levu" and "Wanga lailai," that is, "Large canoe" and "Small canoe." The largest was 90 or 100 feet long, whilst the two smaller were about 50 feet long, the breadth being less than half the length. They are composed of a dense growth of reeds and sedges supporting small living trees 10 to 17 feet in height, swamp ferns, and other smaller vegetation, the whole forming fairly solid standing-ground, and doubtless possessing considerable thickness.

The origin of these floating islands is probably to be found in the circumstance that the dense mass of swamp-vegetation lies on a rocky substratum, and that during some unusually heavy flood large portions of the swampy soil-cap became detached and floated up. A floating island occurs near the sea in the Lauthala district on the Lower Rewa in Viti Levu. The floating island in Derwent-water in the north of England is said to be "a blister of sublacustrine turf." Those in Russia and Hungary, according to Mr. Hanusz, appear to be felted masses of tree-trunks, branches, and marsh-plants thinly covered with soil.¹

I will preface my remarks on the geology of the Wainikoro and Kalikoso plains by observing that this region displays three conspicuous features. In the first place, it is a region of acid rocks, mostly altered tuffs, derived from quartz-porphyrries, the alteration consisting in the deposition of quartz often of the chalcedonic type. In the second place, a silicifying process has been in operation here on an extensive scale, as evidenced by the abundance of silicified corals lying on the surface, especially in the district around the lake and by the abundance of concretions of chalcedony, of fragments of chalcedonic flints, and of portions of white chalcedonic quartz-rock that in places strew the ground. In the third place, earthy limonite, or bog iron ore, has been produced in quantity, particularly around the lake; and in places small round concretions of impure carbonate of iron cover the soil. Before referring more in detail to the different parts of this region, it may be remarked that the silicified corals, flints, iron-ore deposits, &c., of this and other parts of the island are dealt with in Chapter XXV.

This region of acid rocks extends about two miles to the west

¹ *Journal*, Royal Geographical Society, June, 1894.

and south-west of the village of Wainikoro. Here prevail white acid tuffs often decomposing and altered by the formation of secondary quartz. They are derived from the degradation of quartz-porphyrries or rhyolitic rocks. The surface is irregular but the elevation is small, the 100-feet level lying about one mile and the 200-feet level about two miles west of Wainikoro.

The villages of Wainikoro and Kalikoso are from two to three miles apart, the intervening district not attaining a greater elevation than 70 feet above the sea. Decomposing altered white acid tuffs here occur with occasional large blocks, a couple of tons in weight, of apparently a quartz-porphyry or trachyte with its structure disguised by silicification. Fragments of siliceous concretions, as chalcedony, chalcedonic flints, &c., lie on the surface, the soil being friable and of a deep ochreous red; whilst in places the ground is covered with round marble-sized concretions composed of a mixture of carbonate of iron and limonite which I have described on page 356. A few hundred yards to the north-west of Kalikoso, where there is a little rise, a decomposed quartz-porphyry is exposed displaying rounded crystals of quartz fractured in position, the matrix of the rock being impregnated with chalcedony. In one part of this mound there is a friable white rock, composed of a crumbling mass of small irregular quartz-grains, rarely showing crystal-faces. It appears to be disintegrated quartz-felsite.

In taking the track from Kalikoso to the village of Vungalei, which is distant about $2\frac{1}{2}$ miles to the south-east, one traverses after the first mile, where the acid rocks terminate, a rather more elevated region which rises to a maximum height of 180 feet above the sea. Though the acid rocks give place to a semi-vitreous pyroxene-andesite as described on page 212, small fragments of chalcedonic flints are frequent on the surface over both areas. The district that intervenes between Kalikoso and the landing-place on the Langa-linga River, about two miles in length, is not more than 30 feet above the sea, and is crossed by small sluggish streams, in the beds of which occur numerous fragments of silicified corals, up to 3 or 4 inches in size, belonging to the *Porites* and *Astræan* type. In these stream-beds also occur bits of mamillated chalcedony and of onyx, flattish agates, 3 or 4 inches across, and pebbles of the compact pyroxene-andesite above alluded to, the last probably derived from the south side of the plains.

The plains extend in a north-east direction as far as Numbu, which lies between $2\frac{1}{2}$ and 3 miles north-east of Kalikoso. The

country between these two places is usually elevated between 60 and 100 feet and is never more than 130 feet above the sea. It is known as the Kuru-kuru district. The surface is strewn with the fragments of flints and of a white chalcedonic quartz-rock; whilst the soil is friable and deep-red in colour, limonite in abundant fragments occurring on the ground. Here and there one passes slabs of a hard white silicified tuff, small portions of which are frequent on the surface.

Silicified corals and earthy limonite are to be found in abundance scattered over the surface of the plains immediately surrounding the small lake of Vakalalatha. We also find lying on the ground in this district bits of chalcedony and onyx, portions of chalcedonic flints, and nodules of the size of the fist, which when fractured either disclose the regular layers of the agate or radiating crystals of quartz. The silicified corals occur usually in fragments not over 4 inches across, and include portions of branching corals of the Madrepora habit, bits of massive corals of the Astræan type, small rounded nobs of "Porites" just as one commonly observes on a reef-flat, &c. They have an ancient weathered look, and in some cases it is evident from the existence of boring-shells in the fractured end of a branching coral that it once lay as a dead fragment on the surface of a reef-flat.

In Chapter XXV. the characters of the silicified corals of the island are discussed in detail; and I have there advanced the view that the extensive silicification of the Kalikoso and Wainikoro plains took place during the consolidation of the calcareous muds of a reef-flat whilst the land was emerging. I have already alluded on page 222 to an area of silicification on the neighbouring sea-border between Visongo and Tutu. There can be no doubt that during the last stage of the emergence the present situation of the fresh-water lake near Kalikoso was occupied by the sea, which also extended far over the surrounding plains. The process of silicification would of necessity be restricted to the period that has since elapsed; and the discussion is therefore confined to the nature of the conditions under which this change was induced. As a factor in the process we cannot disregard the acid character of the rocks of the district.

THE UNDU PROMONTORY.

The north-east portion of the island terminates in a long narrow promontory which I have named after Undu Point at its extremity. Commencing at Thawaro Bay and near Tawaki it runs

in a straight line for a distance of between 13 and 14 miles, its breadth varying between $1\frac{1}{2}$ and $2\frac{1}{2}$ miles. Its greatest elevation of nearly 1,600 feet is attained at its western end ; and it diminishes irregularly in height as one proceeds towards Undu Point, where a height of 400 feet is maintained about a mile from the cape. It is bordered by reefs sometimes a mile in breadth, and the reefs prolong the promontory for another three miles beyond Undu Point. As indicated by the 100-fathom line, the submarine contour corresponds to that of the land, and the extent of marine erosion during the existing relations of land and sea is evidently displayed in the breadth of the reefs. I found no sign of upraised reefs ; and although diligent inquiries were made nothing could be learned of any hot springs.

It will be seen from the following remarks that pumice-tuffs, quartz-porphyrries, and oligoclase-trachytes, are the prevailing rocks. On the north side they may be regarded as continuous with the acid rocks of the region extending from near Lambasa to Thawaro Bay. On the south side they commence in the vicinity of Tawaki.

(1) THE DISTRICT EXTENDING TWO AND A HALF MILES WEST OF TAWAKI

When proceeding eastward along the north coast of Natewa Bay one enters the region of acid rocks between 2 and $2\frac{1}{2}$ miles west of Tawaki. Here the country is much broken, picturesque hills with bare precipitous faces rising up near the coast, one of which named Natoto has a rudely conical and truncated form. Grey oligoclase-trachytes having a specific gravity of 2.4 and possessing the characters described on page 308, prevail in the district extending west of Tawaki. Sometimes they occur in mass ; but they often form agglomerates. A singular pitchstone-agglomerate occurs at the coast at the foot of Natoto. The pitchstone, which has a specific gravity of 2.48, is a semi-vitreous form of a hypersthene-augite andesite. It shows abundant small pyroxene prisms in its glassy groundmass and is referred to the prismatic sub-order (5) described on page 289.

(2) NAITHOMBOTHOMBO RANGE

A high range of hills, forming the backbone of this part of the island, extends eastward for about five miles from Thawaro and Tawaki. It is named "Naithombothombo" in the Admiralty

chart. From it rise two conspicuous peaks, Thawaro Peak (1,573 feet) at its western end, where it overlooks the village of that name, and Mount Thuku (1,288 feet) near its eastern end. West of Thawaro Peak this range is connected with the hills beyond by a saddle 600 feet in height, which is ascended when crossing the promontory from Thawaro Bay to Tawaki.

(a) *Thawaro Peak*.—This represents an old "volcanic neck" of agglomerate rising out of the tuffs that are exposed on its slopes to an elevation of about 600 feet. As viewed from the saddle above mentioned, the upper part of the hill presents bare precipitous sides, several hundred feet in height, of agglomerate, the blocks of which are composed of a compact hypersthene-augite andesite (sp. gr. 2.48). It displays a few small phenocrysts of medium andesine and of rhombic and monoclinic pyroxene; and is referred to the prismatic sub-order (5) described on page 289, characterised by prismatic pyroxene in the groundmass.

(b) *South coast between Tawaki and the foot of Mount Thuku*.—The tall cliffs that rise to a height of from 200 to 300 feet behind Tawaki are composed of white tuffs and agglomerate-tuffs derived from the acid rocks of the district. Eastward from Tawaki to the base of Mount Thuku the coast scenery is particularly fine. A little inland a line of hills, named "Na Kula," rises precipitously to a height of 700 or 800 feet, and in the vertical sides are displayed tuffs and agglomerates probably of the character of those above noticed. Light-coloured tuffs are sometimes exposed at the coast in which are inclosed fragments varying in size of a pitchstone¹ (sp. gr. 2.36) approaching in structure a trachytic glass. At one place the tuffs were evidently sedimentary and bedded, the dip being about 15° N.W.

The massive rock most frequently exposed at the coast and on the hill-slopes between Tawaki and Mount Thuku is a quartz porphyry² displaying abundant porphyritic crystals of quartz and felspar in a groundmass originally semi-vitreous but now obscurely felsitic in character. The shore-flat for more than half a mile west of Mount Thuku is strewn with great numbers of detached columnar blocks, 12 to 15 inches across, of a slightly vesicular oligoclase-trachyte of the type described on page 308.

(c) *North coast between Thawaro Bay and the foot of Mount Thuku*.—Coarse and fine tuffs prevail at the coast and on the neighbouring hill-slopes; and in the bare rocky faces of the hills

¹ Described on p. 309.

² Described on p. 310.

inland they are also to be observed. The streams have worn deep gorges into their mass. Towards Thuku they are acid and pumiceous, and are evidently the products of eruption. Towards Thawaro, they are more basic and darker, and are in part at least to be attributed to marine degradation.

(d) *Mount Thuku*.—My ascent of this hill, which is 1,288 feet in height, was made from the north coast. I found it to be composed from the foot to the summit of white pumiceous tuffs without any evident arrangement. It has a narrow top and shows no sign of a crateral cavity. The hills east and west, as viewed from its summit, are ridge-shaped and display nothing in their configuration at all suggestive of craters. The pumice-tuffs of Mount Thuku are non-calcareous, and exhibit greyish pumiceous lapilli in an abundant white matrix formed of fine pumice-debris. Under the microscope it shows the characteristic vacuolar and fibrillar structure; but the material has not the fresh appearance of ordinary pumice and the minute cavities are often filled with alteration products. The two rocky points on the north coast opposite the hill are formed in one case of a somewhat altered oligoclase-trachyte and in the other of a quartz-porphry. Both no doubt represent intrusive masses, the almost horizontal columns, 12 to 15 inches in diameter, of the former indicating a nearly vertical dyke.

(3) THE UNDULANT PROMONTORY EAST OF MOUNT THUKU

East of Mount Thuku the hilly backbone of the promontory is of much less elevation. About three miles to the eastward the highest hill is 630 feet, and thence to within a mile or two of Undu Point the hills retain a height of 400 to 500 feet.

(a) *The north coast between Mount Thuku and the coast village of Nuku-ndamu*.—On this stretch of coast, about five miles in length, the shore-cliffs are composed of white and pale-yellow, coarse and fine stratified pumice-tuffs, the beds being either horizontal or with a gentle dip northward. They are as a rule non-calcareous, and contain some quartz grains and small bits, 1 to 3 millimetres in size, of bottle green compact obsidian, much as one finds in Lipari pumice-tuffs. In general character, both naked-eye and microscopic, they correspond to the Mount Thuku pumice-tuffs above described. Large blocks of basic rocks are occasionally to be observed on this coast, sometimes probably indicating dykes, but in one place near Mount Thuku forming an agglomerate.

The rock is a dark-grey augite-andesite with a specific gravity of 2.77. It is compact and has a hemi-crystalline groundmass.¹

(b) *The south coast between Mount Thuku and Moala, a distance of about five miles.*—Pumice-tuffs and agglomerates are displayed at the coast, the former often bedded and in one place having a dip of 35 or 40 degrees to the north. A quartz-porphyry, somewhat banded and a little altered, and displaying rounded quartz crystals 3 or 4 millimetres in size, is the prevailing massive rock exposed on the hill-slopes and occasionally at the coast. It is well exhibited about a mile east of Mount Thuku. Blocks of a grey oligoclase-trachyte also occur. These rocks are described on pages 308, 309.

(c) *The terminal portion of the promontory from Nuku-ndamu and Moala to Undu Point.*—The same pumiceous tuffs, usually non-calcareous, form the shore-cliffs on the south coast from Moala to Mr. Bulling's station at Ndothiu, which lies about 2 miles from the point. On the corresponding part of the north coast between Nuku-ndamu and Ndothiu these tuffs are often calcareous; and near the first-named place they contain sub-angular bits of coral of the size of a walnut. On the beach at Vunikondi in this locality they are overlain by nearly horizontal beds of basic lava, the upper surface of which when exposed displays the smooth, "ropy" crust of a lava flow. The rock is a dark slightly vesicular augite-andesite, hemi-crystalline in structure, and containing a fair amount of residual glass.² Since the underlying tuffs were evidently deposited on a sea-bottom, it follows that this is a submarine flow. I intended to revisit this locality, but was prevented. A detailed examination of it would be worth undertaking.

From Ndothiu to Undu Point, about 2 miles distant, the interior of the promontory has an undulating surface, the elevation being usually 200 or 300 feet and rising to 400 feet. On the coasts are exposed bedded pumiceous tuffs, steeply inclined and usually calcareous. As displayed in the hill-slopes of the interior they are horizontally stratified and as a rule non-calcareous. These deposits sometimes exhibit a spheroidal arrangement indicative of the proximity of a dyke. In one or two places at the coasts occur basic agglomerates, formed of the same augite-andesite

¹ Referred to genus 13 of the augite-andesites. The felspar-lathes average .1 mm. in length, and there is a little interstitial glass.

² Referred to genus 16 of the augite-andesites. There are two sets of felspar-lathes in the groundmass; the larger, .23 mm. long, are more or less parallel; the smaller, .04 mm. long, form a plexus.

lava-rock of which the Vunikondi beds are composed, but scoriaceous and containing more glass in the groundmass. In the hand-specimen beside me, the steam cavities are of all sizes, from that of a pin-prick to a third of an inch (8 mm.) and are generally elongated.

A careful search of the tuff-deposits in this part of the Undu promontory ought to result in the discovery of remains, both of plants and of marine mollusks. Mr. Chalmers informed me that fossilised tree-trunks occur on the coast near Vunikondi ; but I was unfortunately not able to discover them.

BRIEF SUMMARY OF THE GENERAL CHARACTERS OF THE UNDUL PROMONTORY FROM THAWARO AND TAWAKI TO UNDUL POINT.—One suggestive negative feature of this region is to be found in the absence, as far as I could ascertain, of any trace of a crater. Here also, as in the area of acid rocks extending westward along the north side of the island to near Lambasa, hot springs are not to be found. The prevailing rocks are in the first place the pumice-tuffs, which not only as a rule form the coast-cliffs, but occur inland as high as the summit of Mount Thuku almost 1,300 feet above the sea. They were probably in great part ejected from sub-aërial vents, though no doubt, as in the vicinity of Undul Point, they were often deposited under the sea. The acid and basic tuffs in the vicinity of Tawaki and Thawaro are, as I imagine, largely derived from marine degradation. Next to the pumice-tuffs, massive quartz-porphyrries and oligoclase-trachytes are the characteristic rocks. They are probably in most cases intrusive, and present themselves sometimes as vertical columnar dykes, evidently of considerable dimensions.

The basic rocks, however, are not unrepresented. They occur in one or two places as agglomerates, as in the vicinity of Mount Thuku on the north coast and near Undul Point ; whilst they form "flows" overlying the pumiceous tuffs at Vunikondi. Occasional blocks lying on the surface on the north coast are indications of dykes. The basic rocks, nevertheless, take a very secondary part in the composition of the Undul Promontory. They are in most cases to be referred to the augite-andesites with a specific gravity 2.6 to 2.77 ; but some, as in the case of those forming the agglomerates of Thawaro Peak, are hypersthene-augite andesites with specific gravity of about 2.5. Olivine-basalts are not represented.

The vents, from which the materials forming this promontory were ejected, were arranged in a single straight line for a length of 14 miles. Along this linear fissure, which was probably submarine, vents were at different times formed; and though owing to sub-aerial and marine degradation the present surface has been since shaped and reshaped, their situation may still be recognised in the "necks" of tuff and agglomerate that form the peaks, and in the large dykes or sills of quartz-porphry and oligoclase-trachyte.

CHAPTER XVII

THE VOLCANIC ROCKS OF VANUA LEVU

THE varied character of the volcanic rocks in my collection is brought out in the following Table, where I have grouped about 400 rock-sections, excluding those of the tuffs and finer detrital deposits. The small proportion of plutonic rocks should be noted.

Olivine-basalts	23 per cent.
Augite-andesites	40 " "
Hypersthene-augite-andesites	17 " "
Acid andesites, including hornblende and quartz- andesites, &c.	12 " "
Oligoclase-trachytes, quartz-porphyrries or rhyolites	6 " "
Hypersthene-gabbros and diorites	2 " "
	<hr style="width: 10%; margin: 0 auto;"/> 100

In order to avoid the necessity of frequently describing rocks of the same type it has been found requisite to devise a method of classification. In carrying out this somewhat laborious task I have often been surprised at the readiness with which rocks, the relations of which had been previously very difficult to ascertain, fell into their place in the scheme. Although many of my uncertainties have been thus removed, a large number of doubtful points remain. I venture to think, however, that others may be able to employ and also to extend the method of classification here employed.

The general plan followed has been worked out in detail for the olivine-basalts and the pyroxene-andesites of the more basic type; whilst lack of materials has prevented its further elaboration in the case of the acid andesites, oligoclase-trachytes, quartz-porphyrries, &c. The treatment of all the classes has been uniform, the scheme being the same whether applied to a basalt or to a dacite.

In describing the general method I will take the Augite class. As will be seen in the Synopsis that follows, this class is first

divided according to the absence or presence of a groundmass into two sub-classes, the first referring to the plutonic rocks, which, however, are not represented in my collection, the second comprising the augite-andesites which make up 40 per cent. of the total. These andesites are again divided into four orders, according as the groundmass presents parallel or non-parallel felspar-lathes, or short and stout felspars (orthophyric), or displays a felsitic character. The last two orders are practically unrepresented here, though many examples of them are found amongst the more acid andesites. Each order is then split up into three sub-orders depending on the nature of the pyroxene of the groundmass, whether granular, prismatic, or ophitic.

Each sub-order is broken up into two sections, one displaying plagioclase-phenocrysts, the other without them, or possessing very few of them. The first section is divided into two genera, according to the character of the plagioclase-phenocrysts, whether glassy or opaque, the second genus often comprising rocks allied to the porphyrites. The second or aphanitic section is subdivided into two genera according to the character of the pyroxene-phenocrysts; in the one case they are macroporphyritic; in the other they are either small or absent. The genera are split into four species according to the length of the felspar-lathes, a method which readily separates out the doleritic rocks. In cases where the materials are abundant, the genera have been first divided into porphyritic and non-porphyritic sub-genera, based on the macroporphyritic or the micro-porphyritic character of the plagioclase-phenocrysts, when present. The species can be also split into sub-species, according to the degree of basicity of the rocks, as indicated by the specific gravity.

This method is fully worked out in the later pages and need not be further described here. With abundant material from different regions it appears to me that a ready mode is here afforded of assigning to a rock its place in the scheme. In this way it would be possible to follow the systematist in his method of comparing plants and animals from different localities. To facilitate this end, I have suggested in the synopsis the employment of abbreviations, so that the description of the critical characters of a rock can be condensed into a formula capable of easy interpretation.

As an example of the use of these abbreviations I will take the instance of a common form of augite-andesite which is represented by the formula:—" *Plag, aug, matr, flu, gran, non-phen, parv, 1-2 mm.*" This is the formula for an aphanitic augite-andesite, and it

signifies that it is a rock of the plagioclase-augite class possessing a groundmass showing parallel felspar-lathes (between .1 and .2 mm, in average length) and granular pyroxene, and displaying no phenocrysts of plagioclase or only a very few of small size, whilst pyroxene phenocrysts if present are micro-porphyritic.

As another example the following formula for a type of porphyrite found in this island may be given :—*Plag, hypersth-aug, matr, orth, prism, phen, opac*. This is an andesite in which rhombic and monoclinic pyroxene are associated both in the phenocrysts and in the groundmass where the pyroxene is prismatic and not granular. The plagioclase phenocrysts are opaque and the felspars of the groundmass are of the orthophyric type.

There are one or two points that require further reference. In the first place the early employment in the scheme of the characters of the felspars of the groundmass for distinguishing the orders scarcely seems needed in the cases where they take the lathe-form ; but the importance of its early use is shown in the acid andesites where it is certainly of prime importance in an early stage of the classification to distinguish the rocks by the character of the felspars of the groundmass, whether lathe-like, orthophyric, or felsitic. It may also be objected that the two orders obtained by dividing the lathe group into "parallel" and "non-parallel" divisions are not equivalents of the two other orders, the orthophyric and the felsitic. The distinction, however, between the flow or non-flow arrangement, though in practice not always readily established, is a far-reaching one. On *à priori* grounds the first division might be expected to have no plutonic equivalent ; whilst in the second division, it is easy to trace the gradations through the doleritic stage, where the felspar-lathes are very large, to the granitoid condition. Then, again, the ophitic habit is as a general rule confined to rocks with a doleritic or semi-doleritic groundmass, where the felspar-lathes are coarse and form a mesh-work. Two quite distinct lines of development unite in the felspar-lathes and begin to diverge with the difference in their arrangement in the groundmass.

The nature of the difference between the flow and non-flow arrangement of the felspar-lathes is well brought out in some dykes of basalt and augite-andesite that I examined in this island and also in the Valle del Bove on the Etna slopes. In the outer vitreous portion the felspar-lathes, which are fairly well represented, are all about the same length and are more or less parallel with the sides of the dyke. In the central more crystalline portion two sets of

lathes can be distinguished, one (*A*) corresponding in the average length and in the flow-arrangement with the lathes of the borders, the other (*B*) being about half the length and forming a plexus between the larger parallel lathes. Those of the *A* set, which are those that usually catch the eye in a section, are contemporaneous in their origin with those in the margins of the dyke; whilst those of the *B* set have been subsequently formed. In the preliminary "stiffening" of the first stage of consolidation, the whole mass of the dyke would be affected. To this stage the lathes of the *A* set



Diagram illustrating the two sets of felspar-lathes in a dyke:

- A*, long and parallel, dispersed through the mass.
- B*, short and non-parallel and found only in the centre.

belong; whilst to the later stage of consolidation which would proceed much more slowly in the interior than at the margins of the dyke, the lathes of the *B* set are to be referred. This distinction so plainly illustrated in a dyke must be postulated for all intrusive masses; but I have not yet found it possible to make much use of it. Much ground will have first to be cleared before it can be safely employed, since it is apparent, for instance, that there are often all gradations in a slide between a lathe and a phenocryst, and that the term "phenocryst" is applied to crystals having very different histories.

With regard to the ophitic habit of some of the basaltic rocks the following conclusions may be drawn:

(a) Typical ophitic "plates" are not very common in the slides. More frequently the habit of the pyroxene is semi-ophitic.

(b) This character is as a general rule associated with the plexus or non-fluidal arrangement of the felspar lathes.

(c) The felspar-lathes are nearly always large, frequently averaging more than .2 mm. in length. This coarse doleritic groundmass is almost diagnostic of an ophitic rock.

It is not always possible to allow for the influence of locality in drawing up such a classification as this, since it is well known that in each volcanic region the rocks have a particular facies recognisable in hand-specimens as well as in the slide, though it is not easy to express such a distinction in a definition. Perhaps this is represented in "adaptation" as we find it in the organic world, and the question arises as to the value of such characters for critical purposes. Regional variation plays such an important part that it cannot be ignored in rock-classification.

SYNOPSIS

I. CLASS.—OLIVINE ROCKS (*Plag., oliv.*).

SUB-CLASS.	DIVISION.	ORDER. ¹
<div>I. No groundmass (<i>non-matr.</i>) LIMBURGITES, PERIDOTITES, OLIVINE GABBROS, etc.</div> <div>2. Groundmass (<i>matr.</i>) OLIVINE-BASALTS.</div>	<div>I. Olivine abundant (<i>cop.</i>)</div> <div>2. Olivine relatively scanty (<i>pauc.</i>)</div>	<div>(Not represented in collection.)</div> <div>I. Felspar lathes not in flow-arrangement (<i>non-flu.</i>).</div> <div>2. Felspar lathes in flow-arrangement (<i>flu.</i>).</div> <div>3. Felspar lathes not in flow-arrangement (<i>non-flu.</i>).</div> <div>4. Felspar lathes in flow-arrangement (<i>flu.</i>).</div>

¹ Each division would theoretically also possess an orthophyric and a felsitic order; but these orders are not represented in my collection and need only be mentioned.

II. CLASS.—AUGITE ROCKS (*Plag., aug.*).

SUB-CLASS.	ORDER.
<div>I. No groundmass (<i>non-matr.</i>) GABBROS, in part.</div> <div>2. Groundmass (<i>matr.</i>) BASALTIC ANDESITES; AUGITE-ANDESITES; PYROXENE-ANDESITES in part.</div>	<div>Not represented in collection.</div> <div>I. Felspar lathes not in flow-arrangement (<i>non-flu.</i>).</div> <div>2. Felspar lathes in flow-arrangement (<i>flu.</i>).</div> <div>3. Felspars short and broad (orthophyric, <i>orth.</i>).¹</div> <div>4. Groundmass felsitic (<i>fels.</i>).¹</div>

¹ Not represented in the collection.

III. CLASS.—HYPERSTHENE-AUGITE ROCKS (*Plag., hypersth.-aug.*).

SUB-CLASS.	ORDER.
<p>I. No groundmass (<i>non-matr.</i>) GABBROS, in part.</p> <p>2. Groundmass (<i>matr.</i>) PYROXENE-ANDESITES, in part.</p>	<p>Represented by the Hypersthene-gabbros in collection.</p> <p>I. Felspar lathes not in flow-arrangement (<i>non-flu.</i>).</p> <p>2. Felspar lathes in flow-arrangement (<i>flu.</i>).</p> <p>3. Felspars of the groundmass short and broad (orthophyric, <i>orth.</i>).</p> <p>4. Groundmass granular or presenting a mosaic (felsitic, <i>fels.</i>).</p>

IV. CLASS.—HYPERSTHENE ROCKS.

V. CLASS.—HORNBLLENDE-HYPERSTHENE ROCKS.

VI. CLASS.—QUARTZ-HORNBLLENDE-HYPERSTHENE ROCKS OR DACITES.

These last three classes are merely provisional. They include the Acid Andesites of Vanua Levu, which are all characterised by the prevalence of rhombic pyroxene amongst the phenocrysts and by its predominance or rather by its usually exclusive occurrence in the groundmass. All the classes are capable of being split up into two sub-classes and four orders as in the case of the third class. The characters of these rocks are given in Chapter XXI.

VII. CLASS.—HORNBLLENDE ROCKS.

In this class are included those rocks where hornblende is the only ferro-magnesian mineral. It is only represented by two diorites described on page 251.

VIII. CLASS.—OLIGOCLASE-TRACHYTES.

IX. CLASS.—QUARTZ-PORPHYRIES AND RHYOLITES

} Described in Chapter XXI.

FIRST ORDER OF THE OLIVINE BASALTS.

CHARACTERS.—Olivine in abundance. Felspars of the groundmass not in flow-arrangement.

FORMULA.—*Oliv., matr., cop., non-flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes.	
1. Granular (<i>gran.</i>)	1. Plagioclase phenocrysts (<i>phen.</i>)	1. Glassy plagioclase phenocrysts (<i>vit.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	1 2
		2. Opaque plagioclase phenocrysts (<i>opac.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	1 2
	2. No plagioclase phenocrysts (<i>non-phen.</i>)	3. Large phenocrysts of olivine and pyroxene, over 2 mm. (<i>magn.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	1
		4. Small phenocrysts of olivine and pyroxene under 2 mm. Pyroxene scanty and often absent (<i>parv.</i>)	{ '02—1 mm. '1—'2 " '2—'3 " '3—'5 "	1
2. Prismatic (<i>prism.</i>)	3. <i>Phen.</i> . . 4. <i>Non-phen.</i> . .	5. <i>Vitr.</i> 6. <i>Opac.</i>	{	{ Not represented.
		7. <i>Magn.</i> 8. <i>Parv.</i>		
3. Ophitic (<i>oph.</i>)	5. <i>Phen.</i> 6. <i>Non-phen.</i> . .	9. <i>Vitr.</i> 10. <i>Opac.</i>	{	{ Not represented.
		11. <i>Magn.</i> 12. <i>Parv.</i>		
			'1—'2 mm.	1

SECOND ORDER OF THE OLIVINE-BASALTS.

CHARACTERS.—Olivine in abundance. Felspars of the groundmass in flow-arrangement.

FORMULA.—*Oliv.*, *matr.*, *cop.*, *flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes.	
4. Granular (<i>gran.</i>)	7. Plagioclase phenocrysts (<i>phen.</i>)	13. Glassy plagioclase phenocrysts (<i>vit.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	3 2 1
		14. Opaque plagioclase phenocrysts (<i>opac.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	3
		15. Large phenocrysts of olivine and pyroxene, over 2 mm. (<i>magn.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	2
		16. Small phenocrysts of olivine and pyroxene, under 2 mm. Pyroxene scanty and often absent (<i>parv.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	1 5 2 1
	8. No plagioclase phenocrysts (<i>non-phen.</i>)			
5. Prismatic (<i>prism.</i>)	9. <i>Phen.</i> . .	17. <i>Vitr.</i>	{	{ Not represented.
		18. <i>Opac.</i>		
	10. <i>Non-phen.</i> .	19. <i>Magn.</i>		
		20. <i>Parv.</i>		
6. Ophitic (<i>oph.</i>)	11. <i>Phen.</i> . .	21. <i>Vitr.</i>	{	{ Not represented.
		22. <i>Opac.</i>		
	12. <i>Non-phen.</i> .	23. <i>Magn.</i>		
		24. <i>Parv.</i>		

THIRD ORDER OF THE OLIVINE-BASALTS.

CHARACTERS.—Olivine scanty. Felspars of the groundmass not in flow-arrangement.

FORMULA.—*Oliv., matr., pauc., non-flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes and prisms.	
7. Granular (<i>gran.</i>)	13. Plagioclase phenocrysts (<i>phen.</i>)	25. Glassy plagioclase phenocrysts (<i>vit.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ 1 13 5
		26. Opaque plagioclase phenocrysts (<i>opac.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ 4
	14. No plagioclase phenocrysts (<i>non-phen.</i>)	27. Large phenocrysts of olivine and pyroxene, over 2 mm. (<i>magn.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ Not represented.
		28. Small phenocrysts of olivine and sometimes pyroxene, under 2 mm. (<i>parv.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ Not represented.
	8. Prismatic (<i>prism.</i>)	15. <i>Phen.</i>	{ 29. <i>Vitr.</i> 30. <i>Opac.</i> 31. <i>Magn.</i> 32. <i>Parv.</i>	{ Not represented.
		16. <i>Non-phen.</i>		
9. Ophitic (<i>oph.</i>)	17. <i>Phen.</i>	33. <i>Vitr.</i>	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ 3 1 2
		34. <i>Opac.</i>	{	{ Not represented.
		35. <i>Magn.</i>		
	18. <i>Non-phen.</i>	36. <i>Parv.</i>	{	{ Not represented.

FOURTH ORDER OF THE OLIVINE-BASALTS.

CHARACTERS.—Olivine scanty. Felspar-lathes of the groundmass in flow-arrangement.

FORMULA.—*Oliv.*, *matr.*, *pauc.*, *flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes.	
10. Granular (<i>gran.</i>)	19. Plagioclase phenocrysts (<i>phen.</i>)	37. Glassy plagioclase phenocrysts (<i>vit.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ 2 12 6
		38. Opaque plagioclase phenocrysts (<i>opac.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ 2
	20. No plagioclase phenocrysts (<i>non-phen.</i>)	39. Large phenocrysts of olivine and pyroxene, over 2 mm. (<i>magn.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ Not represented.
		40. Small phenocrysts of olivine and sometimes pyroxene, under 2 mm. (<i>parv.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	{ 2 1
11. Prismatic (<i>prism.</i>)	21. <i>Phen.</i> . . .	41. <i>Vitr.</i>	{	{ Not represented.
		42. <i>Opac.</i>		
12. Ophitic (<i>oph.</i>)	22. <i>Non-phen.</i> . . .	43. <i>Magn.</i>	{ '02—'1 mm.	{ Not represented. 1
		44. <i>Parv.</i>		

FIRST ORDER OF THE AUGITE-ANDESITES.

CHARACTERS.—Felspar lathes or prisms of the groundmass not in flow-arrangement.

FORMULA.—*Aug., matr., non-flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes and prisms.	
1. Granular (<i>gran.</i>)	1. Plagioclase phenocrysts (<i>phen.</i>)	1. Glassy plagioclase phenocrysts (<i>vitr.</i>)	{ '02—'1 mm. '1—'2 ,, '2—'3 ,, '3—'5 ,,	9 5 4
		2. Opaque plagioclase phenocrysts (<i>opac.</i>)	{ '02—'1 mm. '1—'2 ,, '2—'3 ,, '3—'5 ,,	6 4 3 3
		3. Large phenocrysts of augite, over 2 mm. (<i>magn.</i>)	{	{ Not represented.
		4. Small phenocrysts of augite, under 2 mm., or none (<i>parv.</i>)	{ '02—'1 mm. '1—'2 ,, '2—'3 ,, '3—'5 ,,	
	2. No plagioclase phenocrysts (<i>non-phen.</i>)	5. <i>Vitr.</i>	{ '02—'1 mm. '1—'2 ,,	1 2
		6. <i>Opac.</i>	{ '1—'2 ,,	2
		7. <i>Magn.</i>	{	{ Not represented.
		8. <i>Parv.</i>	{	
	3. Ophitic (<i>oph.</i>)	9. <i>Vitr.</i>	{ '02—'1 mm. '1—'2 ,, '2—'3 ,, '3—'5 ,,	1 3 4 7
		10. <i>Opac.</i>	{ '2—'3 mm. '3—'5 ,,	1 1
		11. <i>Magn.</i>	{	3 3
		12. <i>Parv.</i>	{ '2—'3 mm. '3—'5 ,,	

SECOND ORDER OF THE AUGITE-ANDESITES.

CHARACTERS.—Felspar-lathes of the groundmass in flow-arrangement.

FORMULA.—*Aug., matr., flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of Specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes and prisms.	
4. Granular (<i>gran.</i>)	7. Plagioclase phenocrysts (<i>phen.</i>)	13. Glassy plagioclase phenocrysts (<i>vit.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	10 10 4 1
		14. Opaque phenocrysts of plagioclase (<i>opac.</i>)	{ '02—'1 mm.	2
	8. No (or very few and small) plagioclase phenocrysts (<i>non-phen.</i>)	15. Large phenocrysts of augite, over 2 mm. (<i>magn.</i>)	{	{ Not represented.
		16. Small augite phenocrysts, under 2 mm. or none (<i>parv.</i>)	{ '02—'1 mm. '1—'2 " '2—'3 " '3—'5 "	12 14 4 3
		17. <i>Vitr.</i>	'1—'2 mm.	1
5. Prismatic (<i>prism.</i>)	9. <i>Phen.</i> . . .	18. <i>Opac.</i> . . . . .	. . . . .	{ Not represented.
		19. <i>Magn.</i> . . . . .	. . . . .	{ Not represented.
	10. <i>Non-phen.</i> . .	20. <i>Parv.</i>	{ '02—'1 mm. '1—'2 "	4 4
		21. <i>Vitr.</i>	'1—'2 mm.	3
6. Ophitic (<i>oph.</i>)	11. <i>Phen.</i> . . .	22. <i>Opac.</i> . . . . .	. . . . .	{ Not represented.
		23. <i>Magn.</i> . . . . .	. . . . .	{ Not represented.
	12. <i>Non-phen.</i> . .	24. <i>Parv.</i>	{	{ Not represented.

FIRST ORDER OF THE HYPERSTHENE-AUGITE ANDESITES.

CHARACTERS.—Felspar-lathes not in flow-arrangement.

FORMULA.—*Hypersth.-aug., matr., non-flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes.	
1. Granular (<i>gran.</i>)	1. Plagioclase phenocrysts (<i>phen.</i>)	1. Glassy plagioclase phenocrysts (<i>vit.</i>)	{ '02—'1 mm. '1—'2 "	12 4
		2. Opaque phenocrysts of plagioclase (<i>opac.</i>)	{	{ Not represented.
	2. No plagioclase phenocrysts (<i>non-phen.</i>)	3. Large phenocrysts of pyroxene, over 2 mm. (<i>magn.</i>)	{	{ Not represented.
		4. Small pyroxene phenocrysts, under 2 mm., or none (<i>parv.</i>)	{ '3—'5 mm.	1
2. Prismatic (<i>prism.</i>)	3. <i>Phen.</i> . . .	5. <i>Vitr.</i>	{ '02—'1 mm. '1—'2 "	2 2
		6. <i>Opac.</i>	{ '02—'1 mm. '1—'2 "	1 1
	4. <i>Non-phen.</i> .	7. <i>Magn.</i>	{	{ Not represented.
		8. <i>Parv.</i>	{	
3. Ophitic (<i>oph.</i>)		{ 9 10 11 12 }	{	{ Not represented.

SECOND ORDER OF THE HYPERSTHENE-AUGITE ANDESITES.

CHARACTERS.—Felspar-lathes in flow-arrangement.

FORMULA.—*Hypersth.-aug., matr., flu.*

SUB-ORDER.	SECTION.	GENUS.	SPECIES.	Number of specimens.
Pyroxene of the groundmass.	Presence or absence of plagioclase phenocrysts.	Character of the phenocrysts.	Length of felspar lathes.	
4. Granular (<i>gran.</i>)	7. Plagioclase phenocrysts (<i>phen.</i>)	13. Glassy plagioclase phenocrysts (<i>vitr.</i>)	{ '02—'1 mm. '1—'2 „	{ 9 2
		14. Opaque phenocrysts of plagioclase (<i>opac.</i>)	{	{ Not represented.
	8. No plagioclase phenocrysts (<i>non-phen.</i>)	15. Large phenocrysts of pyroxene, over 2 mm. (<i>magn.</i>)	{	{ Not represented.
		16. Small pyroxene phenocrysts, under 2 mm., or none (<i>parv.</i>)	{	{ Not represented.
5. Prismatic (<i>prism.</i>)	9. <i>Phen.</i> . .	17. <i>Vitr.</i>	'02—'1 mm.	2
		18. <i>Opac.</i>	'02—'1 mm.	4
	10. <i>Non-phen.</i> .	19. <i>Magn.</i> . . . . .	. . . . .	{ Not represented.
		20. <i>Parv.</i>	{ '02—'1 mm. '1—'2 „	{ 4 2
6. Ophitic (<i>oph.</i>)	. . . . .	{ 21 22 23 24 }	. . . . .	{ Not represented.

THIRD ORDER OF THE HYPERSTHENE-AUGITE ANDESITES.

CHARACTERS.—Felspars of the groundmass short and stout (orthophyric).

FORMULA.—*Hypersth.-aug., matr., orth.*

REMARKS.—The same classification is to be employed here as in the case of the two previous orders, but as the rocks in my collection that belong to this order are not numerous (nine sections), it will be sufficient to refer to the general remarks on the order on p. 290.

FOURTH ORDER OF THE HYPERSTHENE-AUGITE ANDESITES.

CHARACTERS.—Groundmass presenting a rudely granular appearance or blurred mosaic (microfelsitic).

FORMULA.—*Hypersth.-aug., matr., fels.*

REMARKS.—My sliced specimens (five) are too few for the elaboration of this order to which the classification employed for the other orders is scarcely applicable. This is due to the partial decomposition or imperfect development of the pyroxene of the groundmass. The general characters of the order are given on p. 291.

THE PLUTONIC ROCKS.

These rocks are very infrequent and are for the most part hypersthene-gabbros or norites, with a few representatives of diorites¹ without pyroxene. True plutonic rocks did not come under my observation in the western half of the island (west of Lambasa and Savu-savu), those of Mount Thoka-singa in the Ndrandramea district making the nearest approach (see p. 302). The localities in which they were found are below enumerated:—

No.	Nature of rock.	Locality.	Mode of occurrence.	Page.
1	Hypersthene-gabbro	Avuka Range between Lambasa and Mbuthai-sau	Probably forms the axis of the range.	180
2	Ditto	Nawi, at the head of the Vui-na-savu River	Deep-seated.	211
3	Ditto	Valanga Range between Savu-savu and Natewa Bays	Probably forms the axis of the range.	182
4	Ditto	Ridge at the head of Na Kula valley between Savu-savu and Natewa Bays.	Ditto.	184
5	Hornblende-gabbro.	Ditto	Ditto.	184
6	Diorite	Vunimbua River, on south side of the Mariko Range	Loose blocks in river-bed.	182
7	Ditto	Coast cliffs west of the Salt Lake Passage	Large block in agglomerate-tuff.	193

¹ I apply the term "diorite" to granitoid rocks formed entirely of plagioclase and hornblende.

THE HYPERSTHENE-GABBROS.—These rocks also contain monoclinic pyroxene, and are the plutonic equivalents of the hypersthene-augite-andesites which as a rule prevail in the localities where these rocks occur. They are usually dark grey or steel-grey in colour with a specific gravity ranging from 2·7 to 2·84 and have a granitoid aspect. The following characters are common to all the specimens.

• They display a mixture of plagioclase and pyroxene, the last filling up the spaces between the felspars and apparently of later formation. The plagioclase crystals, which are 1 to 2 mm. in size, are opaque; and since they are traversed by numerous fine fissures filled with dust-like decomposition products, their appearance is often semi-saussuritic. They are much cross-macled, are at times zoned, and give lamellar extinctions of andesine-labradorite (20° — 30°). . . . The pyroxene includes both the rhombic and monoclinic forms, the last with extinction angles of over 30° . They may be associated or may occur as separate crystals, the rhombic prevailing in the less basic and the monoclinic in the more basic rocks. The rhombic pyroxene is usually more or less converted into bastite which by further change passes into a chloritic material; whilst the augite sometimes undergoes the diallagic change resulting from schillerisation.

Some special features are presented by rocks from different localities. That from Nawi is most basic and looks like a diallag-gabbro. That from the Valanga Range (sp. gr. 2·75) contains some quartz, apparently secondary and filling up the interspaces. The rock from the Na Kula Ridge shows traces of a groundmass; but it comes near the plutonic type.

A HORNBLENDE-GABBRO.—This granitoid rock, which is from the Na Kula Ridge, has a specific gravity of 2·72. Hand-specimens display large porphyritic crystals of hornblende (7 mm. long) in a base of opaque felspar and smaller hornblende. In the slide we observe besides the large crystals of plagioclase and hornblende a little pyroxene; but the mass of the rock consists of greenish-brown hornblende, plagioclase, and some secondary quartz, forming a coarse mosaic with a "grain" of about a millimetre. The hornblende is displayed in regular hexagonal sections, markedly pleochroic, and gives extinctions up to 12° . It shows no dark resorption borders; and the larger porphyritic crystals have the same characters. Almost all the plagioclase of the rock is traversed by numerous fine fissures, and often acquires a semi-saussuritic appearance from the presence of dust-like decom-

position products. The lamellar extinctions indicate andesine-labradorite. The quartz occurs mostly in nests. The pyroxene is formed of large grains of both the monoclinic and rhombic types.

THE DIORITES.—The rock forming blocks in the Vunimbua River has a specific gravity of 2.78 to 2.8. It is a pretty rock showing long black blades of hornblende, 10 mm. in length, in an opaque felspar base. In the slide the hornblende, which is dark brown and markedly pleochroic, shows six-sided sections with characteristic prismatic cleavage lines, the longitudinal sections giving extinctions up to 15° . The borders in some cases display traces of resorption. The felspar (plagioclase) is in the form usually of broad regular crystals, 3 to 4 mm. in size, and giving extinctions of andesine-labradorite (28°); they are "clouded" through the presence of fine alteration products associated with numerous fissures. The relation between the hornblende and the plagioclase is not constant. This appears to be partially due to the occurrence of traces of a groundmass.

The diorite forming blocks in the agglomerate of the coast cliffs, west of the Salt Lake Passage, is a remarkable rock showing large blackish hornblende crystals, in the shape of blades 25 mm. long and 3 or 4 mm. broad, set in a base of opaque plagioclase felspar which surrounds the hornblende. The last-named is deep-brown, very pleochroic, yields extinctions up to 22° , and displays but little evidence of resorption. The plagioclase is irregular in shape and exhibits broad lamellæ giving extinctions of acid labradorite (28° — 30°). It is traversed by numerous fine fissures filled with decomposition products and contains abundant dust-like materials. (Spec. grav. 2.8).

CHAPTER XVIII

THE VOLCANIC ROCKS OF VANUA LEVU (*continued*)

OLIVINE CLASS

SUB-CLASS II

THE OLIVINE BASALTS (*Plag, oliv, matr.*)

THIS sub-class includes the plagioclase-olivine-basalts. Although these rocks are not the most numerous of the basic rocks, they are well represented in the island, being in great part confined to the western half, and being especially characteristic of the districts of Wainunu and Solevu and of the mountains of Seatura and Naivaka. It will be seen from the Synopsis that this sub-class is split up into two divisions, according to the relative abundance of the olivine. Many of the rocks are grey basalts with the olivine more or less hematized; but the majority are blackish with the olivine usually more or less serpentinised. In the typical blackish rocks there is a little dark opaque interstitial glass. In the grey basalts the groundmass is as a rule holo-crystalline. The specific gravity ranges generally from 2.8 to 3.

It will be noticed in the scheme that the "prismatic" sub-orders, where the pyroxene of the groundmass is for the most part in prisms, are scarcely represented. The "ophitic" sub-orders are poorly represented, since they only include about 10 per cent. of the total. The ophitic olivine-basalts are indeed mostly confined to the division where the olivine is scanty, and the feldspars of the groundmass are for the most part not parallel, the plexus arrangement, as will be often pointed out, being almost essential for the development of the ophitic structure. With the basaltic andesites, which cannot always be sharply separated from the basalts with

scanty olivine, the proportion of ophitic rocks is much higher, probably about 20 per cent. The pyroxene in the olivine-basalts is nearly always augite, intergrowths with rhombic pyroxene being only occasionally observed.

I. DIVISION OF THE OLIVINE-BASALTS

CHARACTERS.—Abundant olivine.

FORMULA.—*Oliv, matr, cop.*

These rocks are characterised by abundant olivine usually as phenocrysts but sometimes represented in the groundmass. When a basalt presents much of this mineral in an ordinary hand-specimen and displays at least five or six phenocrysts in a slide, it is placed in this division. Olivine-basalts of this character are well exhibited in the hills around Solevu Bay and in the neighbouring Seatovo Range. They are also fairly represented on the northern slopes of Mount Seatura, on the coast between the Wainunu River and Nandi Bay, and on the Wainunu basaltic tableland. In the Ulu-i-ndali Range, which lies east of the Wainunu estuary, they are especially frequent. Whilst confined mostly to the portion of the island west of Savu-savu Bay, they occur sporadically in other localities to the eastward, as in Na Suva-suva Hill and in some parts of the Natewa Peninsula. The grey basalts, which form one-third of the total, are chiefly characteristic of the hill of Ulu-i-ndali, of the Solevu district, and of the northern slopes of Seatura. Whilst the blackish basalts usually compose the flows, the grey basalts form dykes and volcanic necks.

Two-thirds of these olivine-basalts belong to the order presenting flow-structure and almost all (28 out of 29) are included in the sub-order exhibiting granular augite in the groundmass. The ophitic structure is displayed in only one case; and the prismatic form of the augites is never a predominant feature.

I. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, non-flu, gran, phen, vitr.*

CHARACTERS.—Abundant olivine. Felspar-lathes of the groundmass not in flow arrangement. Pyroxene of the groundmass granular. Phenocrysts of glassy plagioclase.

DESCRIPTION.—Dark-brown or blackish rocks. Sp. gr. 2.88 to 2.93. Phenocrysts of pyroxene occur in fair quantity in addition

to those of the olivine and plagioclase. The groundmass displays a plexus of feldspars and augite-granules with much magnetite in grains and irregular patches. The interstitial glass is scanty or almost absent. The olivine phenocrysts, of which the larger are 3 to 4 mm. in size, are as a rule hematized at the borders and in the fissures, and are sometimes partially serpentinized. In some cases small crystals of olivine are enclosed in the pyroxene-phenocrysts. The plagioclase phenocrysts do not usually exceed 2 mm. in size. They give lamellar extinctions of 15° — 28° , and are often cross-macled. They generally contain magma-inclusions, which may be arranged in zones, and they sometimes inclose small pyroxene crystals. Their borders are often eroded. The pyroxene-phenocrysts, which frequently are 3 to 4 mm. in size, give extinctions of 30° and over, and may be described as composed of brown augite. It is only at times that intergrowths of rhombic pyroxene occur. They are often twinned and are sometimes eroded and may contain magma and other inclusions. The feldspars of the groundmass, which for the most part form a plexus, are small and stout, their average length varying from .08 to .13 mm., whilst they frequently display lamellar twinning and give extinctions of about 15° (oligoclase-andesine). The pyroxene-granules of the groundmass, which are of brown augite, vary in average size from .02 to .04 mm.

Two of the four species, where the feldspar-lathes are less than .1 mm. and between .1 and .2 mm. in length, are represented in this collection.

2. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, non-flu, gran, phen, opac.*

CHARACTERS.—Abundant olivine. Feldspar-lathes of the groundmass not in flow-arrangement. Pyroxene of the groundmass granular. Phenocrysts of plagioclase opaque white.

DESCRIPTION.—Grey compact-looking rocks; sp. gr. 2.83 to 2.9. Interstitial glass scanty. The olivine phenocrysts, which range up to 5 mm. in size, are more or less hematized; and in extreme cases of this alteration, where schiller-planes are formed, the hand-specimen appears to carry brown mica. There are sometimes small grains of olivine (.1 mm.) in the groundmass. The plagioclase-phenocrysts, varying in size from 2 to 4 mm., owe their opacity partly to their composite character, when they present an aggregate of smaller clear crystals, and partly to multiple

macling. They give extinctions of acid labradorite (25° — 32°). Pyroxene-phenocrysts, when present, are scanty, pale brown, not over 2 mm. in size, and give the large extinctions ($+30^{\circ}$) of augite. In their absence small augites ($\cdot 2$ mm.) are frequent. Fine granules ($\cdot 01$ — $\cdot 03$ mm.) of similar augite, together with magnetite, abound in the groundmass. The feldspars of the groundmass are fairly stout and lathe-like and show at times a few twin-lamellæ which give extinctions of 13° to 20° (medium andesine).

Species represented :

(a) feldspar lathes $\cdot 1$ — $\cdot 2$ mm.

(b) " " $\cdot 2$ — $\cdot 3$ "

3. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, non-flu, gran, non-phen, magn.*

CHARACTERS.—Abundant olivine. Feldspar-lathes of the groundmass not in flow-arrangement. Pyroxene of the groundmass granular. No plagioclase phenocrysts. Large phenocrysts of olivine and pyroxene over 2 mm. in size.

DESCRIPTION.—A remarkable blackish-grey rock. Although somewhat scoriaceous, it has a sp. gr. of 2.91. It displays large phenocrysts of olivine and pyroxene, 4 to 8 mm. in size, in a coarse-textured groundmass of stout feldspars, augite granules, magnetite and a little glass. The olivine is extensively hematized. The pyroxene phenocrysts are of brownish-yellow augite with regular outlines and giving angles of extinction up to 40° . The broad lamellar feldspars of the groundmass, which are on the average $\cdot 3$ to $\cdot 4$ mm. long, give extinctions indicating both acid labradorite (23° to 28°) and medium andesine (16° or 17°). The abundant augite-grains average $\cdot 05$ mm. in size; but the prism form occurs at times.

The species with feldspar-lathes $\cdot 3$ to $\cdot 5$ mm. long is alone represented.

4. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, non-flu, gran, non-phen, parv.*

CHARACTERS.—Abundant olivine. In the groundmass the feldspar-lathes are not in flow-arrangement and the pyroxene is granular. No plagioclase phenocrysts. Small phenocrysts of olivine and occasionally pyroxene under 2 mm.

DESCRIPTION.—A grey coarse-grained rock. Sp. gr. 2.9. It displays abundant small phenocrysts of olivine, all less than a

millimetre in size ($\cdot 2$ — $\cdot 8$ mm.), which are hematised in the fissures and at the borders. The felspar-lathes, which display a few twin-lamellæ giving extinctions of 16° — 18° (medium andesine), vary greatly in size. The smaller are $\cdot 1$ to $\cdot 3$ mm. and the larger $\cdot 3$ to $\cdot 5$ mm. long; but the two are connected by felspars of intermediate length. The abundant augite granules average $\cdot 037$ mm. in breadth. Pyroxene phenocrysts are not represented in the slide. From its coarsely crystalline texture this rock merits the field-name of a grey doleritic basalt; and except in the arrangement of the felspar-lathes it does not differ from the grey doleritic basalts of genus 16.

12. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, non-flu, oph, non-phen, parv.*

CHARACTERS.—Olivine abundant. Felspars of the groundmass not in flow-arrangement. Pyroxene of the groundmass ophitic or semi-ophitic. No plagioclase phenocrysts. Small phenocrysts (under 2 mm.) of olivine and occasionally a few of pyroxene.

DESCRIPTION.—A dark greenish-brown rock, with sp. gr. $2\cdot 91$, showing abundant micro-porphyrific olivine in a groundmass consisting of ophitic pale-brown augite inclosing the felspar-lathes, together with small olivines, patches of magnetite, and a little altered interstitial glass. The olivine-phenocrysts are about $\cdot 5$ mm. in average size and are more or less hematised. The felspar-lathes, which average $\cdot 15$ mm. in length, often show twin-lamellæ that give extinctions of 23° — 30° (andesine-labradorite).

The species with felspar-lathes $\cdot 1$ — $\cdot 2$ mm. long is alone represented.

13. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, flu, gran, phen, vitr.*

CHARACTERS.—Olivine abundant. Felspars of the groundmass in flow-arrangement. Pyroxene of the groundmass granular. Phenocrysts of glassy plagioclase.

DESCRIPTION.—Dark grey or dark brown rocks with sp. gr. $2\cdot 88$ to $2\cdot 99$. Phenocrysts of olivine, pyroxene, and plagioclase occur in a groundmass showing partially parallel felspar-lathes abundant pyroxene grains, and fine magnetite, residual glass being scanty or absent. The olivine-phenocrysts do not exceed 3 or

4 mm. in size and in some rocks are less than 1 mm. They are usually more or less serpentinised and hematised at the borders and in the cracks; but sometimes they are almost fresh and present regular outlines. In some rocks the olivine also occurs as grains (.3 mm.) in the groundmass. When the phenocrysts of olivine have blackish borders they are surrounded by a halo, as though the crystal had attracted the magnetite from the groundmass immediately around. The plagioclase phenocrysts vary from 1 to 3 mm. in size. They often contain abundant magma-inclusions and give lamellar extinctions of 15° to 25° (basic andesine). In some rocks they are rudely parallel. The pyroxene phenocrysts, which are of pale brownish-yellow augite giving extinctions of over 30° , do not usually exceed 3 mm. They present regular octagonal cross-sections and sometimes display lamellar twinning. Occasionally there is a suspicion of intergrowth with rhombic pyroxene. The felspar-lathes, which according to the species vary much in length, at times show a few lamellæ. The augite grains of the groundmass are abundant and are as a rule about .02 mm. in size; but in some rocks they are larger and in others smaller.

This genus may be divided into two sub-genera, the porphyritic sub-genus where the felspar phenocrysts are larger than 3 mm., and the non-porphyritic where they are smaller. All four species, as indicated by the length of the felspar-lathes, are represented.

14. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, flu, gran, phen, opac.*

CHARACTERS.—Olivine abundant. Felspars of the groundmass in flow-arrangement. Pyroxene of the groundmass granular. Opaque plagioclase phenocrysts.

DESCRIPTION.—Dark grey rocks, with sp. gr. 2.9 to 2.93, showing phenocrysts of olivine and pyroxene with opaque whitish phenocrysts of plagioclase in a groundmass of felspar lathes, pyroxene grains, and magnetite, with occasional fine olivine. The olivine phenocrysts, which are sometimes 5 or 6 mm. in size, are often deeply eroded. They are at times so extensively hematised along the schiller-planes that they appear like brown mica. The plagioclase phenocrysts owe their opacity in part to their consisting of an aggregate of lesser crystals which are clear and glassy and give lamellar extinctions of 20° to 30° (andesine labradorite). They do not usually exceed 3 mm. and are sometimes scanty.

The pyroxene phenocrysts, which are at times infrequent, may be 5 mm. in size. They are of pale yellowish-brown augite, giving extinctions of 40° . The felspar-lathes are rarely lamellar; but in one such case the angle of extinction was 17° (medium andesine). The grains of augite in the groundmass average .02 mm. in diameter.

The only species represented is that with the felspar-lathes .1 to .2 mm. long.

15. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, flu, gran, non-phen, magn.*

CHARACTERS.—Abundant olivine. In the groundmass the felspars are in flow-arrangement and the pyroxene is granular. No plagioclase phenocrysts, but large phenocrysts, over 2 mm., of olivine and pyroxene.

DESCRIPTION.—This genus includes the most basic rocks represented in my collection. They are compact heavy blackish rocks with sp. gr. 3 to 3.1, and display large porphyritic crystals of olivine and pyroxene often 3 or 4 mm. in size. The olivine phenocrysts may be fairly fresh with clean outlines, or they may be deeply eroded and stained by iron oxide, or they may be passing into serpentine. The pyroxene phenocrysts may be either eroded or possess regular outlines. They are of pale brown augite and give extinctions over 30° . The pyroxene granules, which average .02 mm. and are very abundant, are of the same augite. The felspar-lathes are relatively scanty. In the two rocks here included they average in length .06 mm. and .08 mm. When lamellæ can be recognised they give extinctions of 30° — 40° (labradorite). The untwinned lathes give extinctions of 20° — 28° (labradorite).

The only species represented is that with felspar-lathes less than .1 mm. in length.

16. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, cop, flu, gran, non-phen, parv.*

CHARACTERS.—Abundant olivine. In the groundmass the felspar-lathes are in flow arrangement and the pyroxene is granular. There are no plagioclase phenocrysts; but there are numerous small phenocrysts, under 2 mm. in size, of olivine and occasionally a few of pyroxene.

DESCRIPTION.—As a highly basic genus this ranks next to the preceding one, the specific gravity of the rocks ranging from

2·91 to 3·01. All the four species indicated by the varying length of the felspar-lathes are represented in my collection. The rocks of the first two, with the felspars averaging less than ·1 mm. and between ·1 and ·2 mm., are compact aphanitic basalts, only displaying an occasional small phenocryst of augite and blackish-grey or bluish-black in colour. Those of the last two species, with the average length of the felspar-lathes ·2—·3 mm. and ·3—·5 mm. respectively, are lightish-grey coarse-textured rocks of the doleritic type. In all the rocks no pyroxene phenocrysts are displayed in the slide; and the olivine phenocrysts, which are very numerous, do not usually exceed 1 mm., though occasionally the average size is 1·3 mm., and not infrequently it is only ·5 mm. In some cases where the larger olivine phenocrysts lie athwart the current of the felspar-lathes, the smaller (·5 mm.) lie with their long axes parallel to the flow. The olivine is either fresh, or it may be beginning to serpentinise in the cracks, or it may be in part hematized. The crystals may have regular outlines, or they may be rounded and sometimes deeply eroded. The pyroxene granules of the ground-mass are of pale-brown augite, and average ·01 to ·03 mm. in size. Occasionally a few prism forms occur, giving extinctions of 30° to 40°. In the case of the more compact rocks, with the felspar-lathes averaging less than ·2 mm. in length, lamellar twinning is but scantily to be noticed in the lathes, which give extinctions measured from the long axis of 20° to 25° and by the twin lamellæ of 30° to 35°, indicative of acid labradorite in both instances. With the coarser doleritic grey basalts, where the felspar-lathes are stouter and have an average length exceeding ·2 mm., lamellar twinning is more frequent; the extinctions afforded by the lamellæ range between 15° and 25° (medium andesine). Residual glass is scanty in these rocks, and in the grey dolerites it is often difficult to recognise any.

2. DIVISION OF THE OLIVINE-BASALTS

CHARACTERS.—Scanty olivine.

FORMULA.—*Oliv, matr, pauc,*

25. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, pauc, non-flu, gran, phen, vitr.*

CHARACTERS.—Olivine scanty. Felspars (lathes and prisms) of the groundmass not in flow-arrangement. Pyroxene of the groundmass granular. Glassy plagioclase phenocrysts.

DESCRIPTION.—About two-thirds of these rocks have a common facies, being closely similar in appearance, brownish-black in colour, and with spec. grav. usually between 2·84 and 2·92. They belong to the species with the felspar-lathes ·1 to ·2 mm. in length. They are essentially the rocks of the old submarine basaltic flows; and they are often columnar, the columns being 2 to 4 feet across. My remarks will mainly apply to this predominant group.

To the eye they are somewhat compact and show scattered porphyritic crystals of plagioclase. In the slide they display numerous phenocrysts of plagioclase, with a few of olivine and pyroxene, in a groundmass formed of stout lamellar felspar-lathes and small prisms forming a plexus with granular augite in the meshes. There is a good deal of magnetite and generally scanty residual glass. The plagioclase phenocrysts are usually 2 to 3 mm. in size, but they may be smaller (1 to 2 mm.) or larger (3 to 5 mm. or more) when the rock has a porphyritic appearance.¹ They are often cross-macled and at times show zoning. In many slides two kinds are distinguished by the extinctions which indicate in one case medium andesine (15° to 22°) and in the other acid labradorite (27° to 32°). They contain inclusions of the magma and are often eroded. The pyroxene phenocrysts are of pale brown augite, scanty and small, and give extinctions of 30° to 40°. They are sometimes twinned and may be eroded and contain inclusions of the magma. The olivine phenocrysts, which do not usually exceed 2 or 3 mm., are mostly rounded, but sometimes have the regular outlines, and are in various stages of serpentinisation. The felspars of the groundmass, which average ·17 mm. in length, are mostly stout and lamellar; but they exhibit all transitions from the lathe-shape with one or two lamellæ to broad multi-lamellar prisms where the breadth is half the length. They give lamellar extinctions averaging 15° to 18° (andesine). The augite granules of the groundmass are pale brown and average ·02 to ·03 mm. in size. In a few cases they are larger (·05 mm.) which is an indication of an approach to the ophitic type. In most slides occur a few small augites of prism-form, two or three times the size of the granules, which give extinctions of over 30°. Where the phenocrysts of augite are very scanty or absent, there exist large grains (·1 mm.) of an intermediate size. The magnetite is often abundant, occurring in crystals, rods, and irregular masses, the last associated often with

¹ According to the size of the plagioclase phenocrysts, whether averaging less than or more than 3 mm. in size, these rocks may be divided into a non-porphyritic and a porphyritic sub-genus.

the interstitial glass which is present in small quantities in most rocks, being greenish or brownish and showing fibrous devitrification.

In some localities semi-vitreous rocks referable to this genus are frequent. This is especially the case in the Naivaka peninsula, where the rocks show a fair amount of glass in the groundmass, the porphyritic augite being well developed, whilst the pyroxene of the groundmass is only in part differentiated. Three of the four species are here represented. Those with large felspar-lathes (2—3 mm. long) and coarse augite granules (0.5) approach the semi-ophtitic rocks included in genus 33.

26. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv*, *matr*, *pauc*, *non-flu*, *gran*, *phen*, *opac*.

CHARACTERS.—Olivine scanty. In the groundmass the felspar-lathes and prisms are not in flow-arrangement and the pyroxene is granular. The plagioclase phenocrysts are opaque.

DESCRIPTION.—Dark grey porphyritic rocks, which, from the opacity of the felspar phenocrysts, look like porphyrites. They are not very frequent and occur mostly on the northern slopes of Mount Seatura. Two different types occur in my collection which may be regarded as sub-genera. In the most basic kind, where the sp. gr. is 2.86 to 2.89, the plagioclase phenocrysts, 2 to 3 mm. in size, owe their opacity chiefly to their aggregate structure. They give lamellar extinctions (15° — 30°) of andesine labradorite. Porphyritic olivine is scanty and more or less hematized; but a fair amount of olivine grains, less than 1 mm., occur in the groundmass. Pyroxene phenocrysts are scanty, but micro-porphyritic pale brown augite (1 mm.) is frequent. In the groundmass are found stoutish felspar-lathes, averaging 2 mm. long, together with an abundance of fine augite granules (0.01—0.02 mm.) and fine magnetite, the residual glass being scanty. . . . In the other type the sp. gr. is 2.75; and the plagioclase phenocrysts 4 to 6 mm. in size give extinctions of andesine and acid labradorite (10° — 30°). There is an approach to the orthophyric structure in the groundmass, as is indicated by the number of short broad felspars, averaging 2 mm. in length and giving lamellar extinctions of acid and basic andesine. The granular augite of the groundmass is coarse (0.04 mm.), and occasional prism-forms give extinctions of 40° .

33. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, pauc, non-flu, oph, phen, vitr.*

CHARACTERS.—Olivine scanty. In the groundmass the felspar-lathes are not in flow-arrangement and the pyroxene is ophitic or semi-ophitic. Plagioclase phenocrysts glassy.

DESCRIPTION.—These brownish-black rocks are all of the semi-ophitic type. Although no ophitic "plates" occur in the slide, the augites of the groundmass have no longer the granular form, but are large, .08—.1 mm. in size, and tend to invest the felspar-lathes. The specific gravity ranges from 2.78 to 2.86. As in other of the ophitic and semi-ophitic rocks of this collection (genera 9, 10, 12, of the augite-andesites), the large size of the felspar-lathes (.2—.3 mm. long) of the groundmass gives a doleritic texture in the slide. In most of the other characters these rocks approach those of genus 25 which possess felspar-lathes more than .2 mm. in length. But they are more often semi-vitreous, and display a considerable amount of dark smoky glass showing numerous magnetite rods and skeletal crystals with fibrous devittrification. The plagioclase phenocrysts, which vary much in size in different rocks (in some 2 or 3 mm., in others 4 or 5 mm.), give extinctions of andesine labradorite (20°—35°). They are often eroded and contain numerous large black inclusions of the magma. The pyroxene phenocrysts, which are of pale-brown augite, often have an aggregate-structure, having been formed *in situ*. Others again consist of single crystals and have been much affected by the magma. The olivine phenocrysts, which are at times deeply eroded, are generally small and in part serpentinised.

37. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, pauc, flu, gran, phen, vitr.*

CHARACTERS.—Olivine scanty. In the groundmass the felspar-lathes are in flow-arrangement and the pyroxene is granular. Glassy plagioclase phenocrysts.

DESCRIPTION.—Brownish-black rocks which cannot be distinguished, except in the flow-arrangement of the felspars of the groundmass, from those described under genus 25. Like them they enter into the formation of the basaltic plains of Sarawanga and Mbua and elsewhere. Most of the rocks of this genus group themselves into one type where the felspar-lathes average in

length $\cdot 15$ — $\cdot 21$ mm. The sp. gr. is usually between $2\cdot 87$ and $2\cdot 91$. Though rarely porphyritic, such rocks display to the eye a few small scattered glassy phenocrysts of plagioclase and an occasional grain of olivine. It is to this type of the genus that the following description applies.

In the thin sections they display small plagioclase phenocrysts, with a few of olivine and occasionally of pyroxene, in a groundmass where the flow-arrangement of the felspar-lathes is well marked, the rest of the groundmass being made up of granular augite with magnetite and generally a little residual glass. . . . The plagioclase phenocrysts do not usually exceed 2 mm. in size and contain magma inclusions. Two kinds are often indicated in the same slide by the extinctions, namely, one of medium andesine (17° — 22°), and the other of acid labradorite (28° — 33°). . . . The pyroxene phenocrysts are of pale brown augite; but they are small (less than 2 mm.), scanty, and often absent when their place is taken by microporphyritic augite, $\cdot 2$ mm. in size. . . . The olivine phenocrysts are generally small. Though sometimes showing the long hexagonal sections, they are often rounded and more or less serpentinised. . . . The felspars of the groundmass present more typical lathes than are to be observed in the non-parallel felspars of the rocks of genus 25. The twin-lamellæ, when present, are fewer; but give similar extinctions (15° — 21°) of medium andesine. . . . The augite granules are, as a rule, $\cdot 02$ or $\cdot 03$ mm. in diameter; but occasional more prismatic forms occur, two or three times the length, which give extinctions of over 30° . The magnetite is abundant, and the scanty interstitial glass is green or brown and displays fibrous devitrification.

The following three species, as indicated by the length of the felspar-lathes, are represented in my collection:

- (a) $\cdot 02$ — $\cdot 1$ mm. (b) $\cdot 1$ — $\cdot 2$ mm.
(c) $\cdot 2$ — $\cdot 3$ mm.

38. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, pauc, flu, gran, phen, opac.*

CHARACTERS.—Olivine scanty. In the groundmass the felspar-lathes are in flow-arrangement and the pyroxene is granular. Opaque plagioclase phenocrysts.

DESCRIPTION.—Grey rocks, sp. gr. $2\cdot 78$ to $2\cdot 83$, showing small opaque porphyritic crystals of plagioclase with a few phenocrysts

of olivine and pyroxene in a groundmass of parallel felspar-lathes, augite granules, and magnetite, with very scanty, if any, interstitial glass. . . . The plagioclase phenocrysts, 2 to 3 mm. in size, are often aggregates of smaller crystals. They contain colourless granular inclusions and are sometimes zoned, giving extinctions of medium andesite (15° — 18°), and of andesine labradorite (25° — 29°).

. . . The pyroxene phenocrysts are pale-brown, scanty, 2 to 3 mm. in size, often twinned and give the large extinctions of augite. . . . The olivine phenocrysts, which do not exceed 2 or 3 mm., are deeply eroded by the magma and are hematised and schillerised. Small grains also occur in the groundmass. . . . The felspar-lathes, which in the species here represented average .15 mm. in length, are stout and give lamellar extinctions of andesine (18° — 22°). . . . The augite granules are pale-brown and usually .02—0.03 mm. in diameter.

The only species represented in my collection is that with the felspar-lathes .1—0.2 mm. long.

40. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, pauc, flu, gran, non-phen, parv.*

CHARACTERS.—Olivine scanty. In the groundmass the felspar-lathes are in flow-arrangement and the pyroxene is granular. No plagioclase phenocrysts; but there are a few small phenocrysts of olivine and sometimes of pyroxene under 2 mm. in size.

DESCRIPTION.—Compact-looking non-porphyrific blackish-brown rocks, sp. gr. about 2.9. Occasionally a little vesicular. For the most part dyke-rocks.

In the slide are displayed a few small phenocrysts of olivine and pyroxene in a groundmass formed of more or less parallel felspar-lathes, augite granules, magnetite, sometimes in rods, and a little greenish devitrified residual glass. . . . The pyroxene phenocrysts are of pale-brown augite and are generally less than a millimetre in size. They may be single crystals or they may be formed of an aggregate of a few smaller crystals. . . . The olivine phenocrysts rarely exceed 2 mm. in size and are in part serpentinised. . . . The augite granules vary usually from .01 to .03 mm. in diameter. . . . The felspar-lathes of the rocks in this collection are large, often exceeding .2 mm. in length, giving the rock a doleritic texture in the slide. In a single slide they may range from .1 to .6 mm. When lamellar they give extinctions of 15° to 25° (basic andesine).

Two species are represented in this collection :—

(a) with felspar-lathes '2—'3 mm.

(b) " " " '3—'5 "

44. GENUS OF THE OLIVINE-BASALTS

FORMULA.—*Oliv, matr, pauc, flu, prism, non-phen, parv.*

CHARACTERS.—Olivine scanty. In the groundmass the felspar-lathes are in flow-arrangement and the pyroxene is in great part prismatic. There are no phenocrysts of plagioclase ; but there are a few small phenocrysts of olivine and sometimes of pyroxene, less than 2 mm. in size.

DESCRIPTION.—A dark grey compactish rock ; sp. gr. 2·9 ; showing a little macroscopic olivine ; forming a dyke in the tuffs on the summit of the hill of Vatui (p. 54).

In the section it exhibits a few phenocrysts of olivine (more or less serpentinised) and of augite in a groundmass formed of stout augite prisms and small augite granules with felspar-lathes, magnetite, and a little devitrified yellowish interstitial glass. The augite prisms and the felspar-lathes are in flow-arrangement. . . . The pyroxene phenocrysts, which are pale brown and give extinctions of over 30° from the single cleavage-lines, may be aggregates of five or six smaller crystals or single crystals presenting sometimes lamellar twinning. The first are doubtless formed *in situ*. The second though showing regular outlines may have a nucleus giving a different extinction and possessing eroded margins. The stout augite prisms of the groundmass, which are occasionally twinned, have an average length of '2 to '3 mm. and give angles of extinction with the long axis of 30° to 40°. The felspar-lathes average only '07 mm. in length and afford extinctions, when untwinned, of 18° to 24° (acid labradorite).

The only species represented is that where the average length of the felspar-lathes is between '02 and '1 mm.

CHAPTER XIX

THE VOLCANIC ROCKS OF VANUA LEVU (*continued*)

AUGITE CLASS

SUB-CLASS II

AUGITE-ANDESITES INCLUDING THE BASALTIC ANDESITES (*Plag, aug, matr.*)

THIS sub-class, which comprises 40 per cent. of the volcanic rocks, is characterised by the absence of olivine on the one hand, and by the rarity or absence of rhombic pyroxene on the other. On the basic side it shades into the olivine-basalts through the basaltic andesites, and on the acid side by intermediate stages into the hypersthene augite andesites; and for these reasons it is not always possible to draw a sharp line of distinction. In cases where a hand-specimen displays no macroscopic olivine and where a solitary small phenocryst of olivine is alone observed in the slide, it should be referred to this sub-class; and here also all doubtful specimens as regards the occurrence of olivine should be placed. When the question of the occurrence of rhombic pyroxene arises, it should be remembered that the great prevalence of monoclinic pyroxene amongst the phenocrysts and the practical absence of rhombic pyroxene from the groundmass are essential characteristics of this sub-class. Rhombic pyroxene is only indicated at times by intergrowths in the phenocrysts.

The basaltic andesites enter into the formation of old "flows," as in the Mbua and Ndama plains. The other rocks enter principally into the composition of dykes, necks, and agglomerates.

I. GRANULAR SUB-ORDER (AUGITE-ANDESITES)

FORMULA.—*Aug, matr, non-flu, gran.*

I. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, gran, phen, vitr.*

CHARACTERS.—In the groundmass the felspar-lathes and prisms are not in flow-arrangement and the augite is granular. Phenocrysts of glassy plagioclase.

DESCRIPTION.—These rocks frequently form dykes ; and it is probable that most of the instances where the nature of the exposure could not be ascertained also fall into this category. They are dark-brown or blackish, and their sp. gr. ranges, except in the semi-vitreous rocks, from 2·7 to 2·83. They are sometimes vesicular, and rocks with abundant interstitial glass are common. They admit of grouping into two sub-genera according to the size of the plagioclase phenocrysts :

- (a) Porphyritic, where the average size is 3 mm. or over.
- (b) Non-porphyritic „ „ „ „ „ less than 3 mm.

Nearly all the rocks in my collection belong to the second group.

In the sections they display phenocrysts of plagioclase and occasionally of pyroxene in a groundmass formed of a plexus of felspar-lathes, augite granules, magnetite, and usually a fair amount of smoky more or less opaque interstitial glass. . . . The felspar phenocrysts, which are sometimes abundant, give lamellar extinctions of andesine labradorite (15° to 30°). They are frequently small (1 to 2 mm.) and contain often many magma-inclusions. Whilst the corroded aspect of some indicate that they belong to an earlier period, the aggregate character and regular outlines of others suggest that they have been produced in position. . . . Pyroxene phenocrysts are absent in half the rocks. When present they are generally small and of a pale augite which gives extinctions of 30° . Their size does not usually exceed 2 mm. ; and they may consist of single crystals (sometimes twinned) or of an aggregate of smaller crystals. At times there is a suspicion of intergrowth with rhombic pyroxene ; but no phenocrysts formed alone of that mineral occur. . . . The augite granules of the groundmass as a rule vary from '02 to '04 mm. in diameter. Occasional prism-forms giving large extinctions occur. . . . The felspar-lathes vary much in length in different rocks. In some they average as little as '05 mm., and in others as much as '2 mm. ; but the doleritic type with yet longer lathes is not represented in the collection except among

the altered rocks. Most of the lathes show a single median twin-line, and when broader they display twin-lamellæ. The angles of extinction indicate acid and basic andesine.

Three out of the eight species distinguished by the length of the felspar-lathes occur in my collection, that with the longest lathes (.3—5 mm.) being not represented.

2. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, gran, phen, opac.*

CHARACTERS.—In the groundmass the felspar-lathes and prisms are not in flow-arrangement and the augite is granular. Opaque plagioclase phenocrysts.

DESCRIPTION.—This genus may be divided into two groups according to the size of the plagioclase phenocrysts, the first "porphyritic," where they average 3 mm. and over, the second "non-porphyritic," where they are smaller than 3 mm., usually not over 2 mm. The former would include some of the "porphyrites," and to this only one of the rocks sliced is to be referred. All the rest belong to the non-porphyritic type; and several of them are rocks that have undergone the propylitic change, as indicated by the formation of pyrites, chlorite, calcite, and other alteration-products.

(a) PORPHYRITIC SUB-GENUS.—A greyish rock, with sp. gr. 2.78, showing abundant porphyritic opaque plagioclase (4 to 7 mm.), from the vicinity of Satulaki. These phenocrysts are often aggregates of lesser crystals, or they may be extensively cross-macled. They are traversed by numerous fine cracks and show much dust-like included material. They are in part corroded by the magma and give evidence of fracture in their present position, the re-union being sometimes effected by the growth of new substance. Their lamellar extinctions (10° to 20°) are those of andesine. The groundmass displays a plexus of stout felspar-lathes, averaging .1 mm. long, with the meshes occupied by coarse augite granules, .03 to .05 mm., with little, if any, interstitial glass. The felspars are often lamellar and give extinctions like those of the phenocrysts.

(b) NON-PORPHYRITIC SUB-GENUS.—Reference will first be made to some of the propylitic rocks of the dykes of the Ndriti Basin which belong to this group (see p. 70). They are greenish or greyish, with sp. gr. 2.76 to 2.8, and often sparkle with pyrites

and contain secondary calcite, sometimes to such an extent that they might be taken at first sight for impure limestones.

The small opaque plagioclase phenocrysts (under 2 mm.), that they contain, are more evident in the slide than in the hand-specimen, and scarcely give a macroscopic character to the rock. They give extinctions (10° to 30°) ranging from those of acid andesine to acid labradorite, and are traversed by numerous cracks occupied by calcitic and other alteration products. The few pyroxene phenocrysts that once existed are now entirely represented by chloritic pseudomorphs. The groundmass displays a doleritic texture, exhibiting a plexus of long felspar-lathes, '2 to '4 mm. in average length, which often present a false resemblance to a flow-arrangement from their aggregation into bundles. They are often clouded by secondary products, but occasionally give lamellar extinctions (20° to 30°) indicating andesine labradorite. The rest of the groundmass is greatly altered, the granular augite and the interstitial glass, which originally existed in fair amount, being replaced by calcite, chlorite, pyrites, and occasionally epidote, so that the rock mass appears largely impregnated with alteration products. In addition there is much secondary magnetite, and in some cases there are a few minute cavities filled with chalcedonic silica and zeolites.

Reference may here be made to a singular rock from Ruku-ruku Bay, which resembles the Ndriti rocks in its propylitic alteration, but the felspar-lathes of the groundmass, '21 mm. in length, give the small extinctions of oligoclase. Spec. grav. 2'61.

Most of the prevailing rocks of Mount Freeland belong to this sub-genus. They are dark grey and show small opaque plagioclase phenocrysts 1 or 2 mm. in size. They usually, however, are more or less altered, the change being often of the propylitic type, calcite, chloritic material, viridite, and occasionally pyrites occurring as alteration products. The specific gravity of the altered rocks is 2'61—2'69; that of the least affected is about 2'76. They all, however, belong to the same genus, displaying small phenocrysts of plagioclase and augite in a groundmass composed of minute stoutish felspar-lathes ('03—'06 mm.), augite granules, magnetite, and a little residual glass. The plagioclase phenocrysts owe their opacity partly to the numerous fine cracks traversing them and partly to the alteration products. The pyroxene phenocrysts, which are mostly of pale yellow augite, display at times intergrowths of rhombic pyroxene.

4. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, gran, non-phen, parv.*

CHARACTERS.—In the groundmass the felspar-lathes and prisms are not in flow-arrangement and the augite is granular. There are no plagioclase phenocrysts, and those of augite when present are small (under 2 mm.).

DESCRIPTION.—Two groups of these rocks occur in my collection. In the one there are vesicular and scoriaceous rocks forming dykes near Nukunase and near the village of Ndriti. They display a plexus of felspar-lathes with abundant smoky more or less devitrified glass, the augite granules not being always differentiated. The felspar-lathes vary from .1 to .2 mm. in average length, and when lamellar give extinctions of basic andesine (25°). There are no pyroxene phenocrysts, and the augite granules when present average .02 mm. in size.

In the other group are included some propylites from the dykes of the Ndriti Basin. They are greyish or greenish rocks, have a sp. gr. of 2.72 to 2.76, sparkle often with pyrites, and contain so much secondary calcite that they effervesce freely with an acid. Except in the rarity or absence of plagioclase phenocrysts, they come near to the propylitic rocks described under genus 2. They usually display a doleritic groundmass exhibiting long felspar-lathes, .2 to .33 mm. in length, which present the same pseudo-flow arrangement from their being gathered into bundles. The alteration corresponds precisely to that previously described, chlorite, epidote, pyrites, &c., occurring in quantity as secondary products.

II PRISMATIC SUB-ORDER OF THE AUGITE-ANDESITES WHERE THE FELSPAR-LATHES ARE NOT IN FLOW-ARRANGEMENT

FORMULA.—*Aug, matr, non-flu, prism.*

The augite-andesites, which display in the groundmass a plexus of felspar-lathes and much prismatic pyroxene, are not frequent in my collection. About half of the specimens belong to agglomerates, whilst the rest are of the massive type, none apparently being obtained from dykes. They admit of the same classification as that generally adopted for the "granular" sub-orders; and it must be not forgotten that granular pyroxene also occurs but is not predominant.

5. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, prism, phen, vitr.*

CHARACTERS.—In the groundmass the felspar-lathes and prisms are not in flow-arrangement and the augite is for the most part prismatic. Plagioclase phenocrysts glassy.

DESCRIPTION.—Except as regards the prismatic pyroxene these rocks do not differ much from the "granular" augite-andesites. Those before me show phenocrysts of plagioclase and sometimes of augite in a groundmass displaying a mesh-work of felspar-lathes, prismatic pyroxene, and much interstitial glass. . . . The plagioclase phenocrysts, 1 to 3 mm. in size, show abundant magma-inclusions arranged either zone-wise or parallel to the twinning-planes. They are often eroded. . . . The phenocrysts of augite, which give extinctions of over 30° , are often rounded and display glass and other inclusions. . . . The prismatic pyroxenes of the groundmass vary in average length from .03 to .08 mm. They have the peculiar pale muddy brown hue characteristic of the prismatic augite in these rocks, and give oblique extinctions up to 30° and over. They may be short and broad or long and slender, and when there is much glass in the rock they resemble the felspar-lathes in their forked and imperfect extremities. Granular pyroxene occurs, but is subordinate. . . . The felspar-lathes, .1 mm. long, are rarely lamellar, and give extinctions measured from their long axis of 20° (basic andesine).

6. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, prism, phen, opac.*

CHARACTERS.—In the groundmass the felspar-lathes are not in flow-arrangement and the augite is for the most part prismatic. The plagioclase phenocrysts are opaque.

DESCRIPTION.—Light and dark grey rocks displaying abundant opaque plagioclase phenocrysts not exceeding 2.5 mm. They are somewhat altered, one of the specimens having a sp. gr. of 2.68.

In the section they exhibit phenocrysts of plagioclase, and occasionally of augite in a groundmass of felspar-lathes, pyroxene prisms and granules (the former predominating), with a fair amount of altered interstitial glass. . . . The plagioclase phenocrysts owe their opacity to the great number of fine and sometimes parallel cracks

filled with alteration products, that traverse them. Although much of their original material has often disappeared, they still display the lamellar twinning of medium andesine (15° to 20°) The phenocrysts of pale yellowish augite, which give the large extinctions of that mineral, exhibit but little alteration, although lying in the same slide with those of the plagioclase. . . . The pyroxene prisms of the groundmass are of the same yellowish augite. They are broad with rounded extremities and are arranged in a loose plexus. . . . The feldspars of the groundmass, which average .1 mm. in length and give extinctions of medium andesine, are either lathe-shaped or short and broad when they display lamellæ. The last-named approach the orthophyric type, and such rocks come near the porphyrites; but I do not feel justified in placing them in a separate orthophyric order.

III OPHITIC SUB-ORDER OF THE AUGITE-ANDESITES WITH THE FELSPARS OF THE GROUNDMASS NOT IN FLOW-ARRANGEMENT.

FORMULA.—*Aug, matr, non-flu, oph.*

These rocks form generally ancient flows. They are for the most part semi-ophitic, large ophitic "plates" being uncommon.

9. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, oph, phen, vitr.*

CHARACTERS.—The felspar-lathes and prisms of the groundmass are not in flow-arrangement. The augite of the groundmass is ophitic or semi-ophitic. Glassy plagioclase phenocrysts.

This genus may be divided into two sub-genera,

(a) Porphyritic, where the average size of the plagioclase phenocrysts is 3 mm. and over.

(b) Non-porphyritic, where the size is less than 3 mm.

A. PORPHYRITIC SUB-GENUS

DESCRIPTION.—Coarse-looking brownish-black porphyritic rocks displaying large plagioclase crystals that often show a play of colours. Their sp. gr. is about 2.8. None of the rocks in my collection are vesicular. On account of the considerable porphyritic development of the plagioclase, the groundmass is relatively diminished, the large phenocrysts occupying about a third of the mass. They form ancient basaltic flows more especially in the

vicinity of the isolated hills and mountains of acid andesite, as around Vatu Kaisia; whilst they may enter into the formation of the low basaltic plains as in the region west and south of the Ndreketi River. They are, however, limited in their extent and occurrence. From the large amount of glass in the groundmass, they may be inferred to belong to flows formed under different conditions from those under which the great basaltic plateaux were formed, where the rock contains but scanty interstitial glass.

In the slide they show the large plagioclase phenocrysts together with a few small plates of ophitic augite in a groundmass displaying in an abundant smoky glass a loose plexus of long stout lathe-like plagioclase prisms partly wrapped around by lesser augites. . . . The plagioclase phenocrysts, which attain a size of 4 to 6 mm., give lamellar extinctions of basic andesine (20° — 27°) and show concentric zone-lines with transmitted light. They often polarise in brilliant colours and are extensively cross-macled. They contain usually abundant inclusions of the magma sometimes arranged zone-wise, and are frequently eroded. . . . Non-ophitic pyroxene phenocrysts are uncommon. In the slide occur one or two small "plates," 1 to 2 mm. in size, of ophitic pale-brown augite, and a number of lesser augites, .2 to .3 mm. in size, which in part wrap around the felspar-lathes and by their aggregation form imperfect ophitic "plates." . . . The long stout felspar-lathes, which are on the average .3 to .45 mm. in length, give lamellar extinctions of 15° to 20° (medium andesine) The copious smoky glass is rendered partially opaque by the abundant development of rods and skeletal crystals of magnetite, and shows the fibrous devitrification arising from the formation of incipient microliths. In some rocks there appear in the smoky glass brownish-yellow patches of the residual magma which under the microscope cannot be distinguished from palagonite.

All but one of the specimens belong to the species where the felspar-lathes average over .3 mm. in length.

B. NON-PORPHYRITIC SUB-GENUS

DESCRIPTION.—Blackish-brown semi-ophitic rocks, sp. gr. 2.74—2.77, frequently of doleritic texture and showing a few small macroscopic plagioclase phenocrysts. They are sometimes vesicular, and form old flows in a few localities, as in the vicinity of Natua in the eastern part of the Ndreketi plains and in the coast district between Lekutu and Wailea Bay.

They display in the slide small plagioclase phenocrysts, often abundant, in a groundmass exhibiting a loose plexus of large lath-shaped felspar prisms, together with occasional small ophitic "plates" of augite and numerous smaller semi-ophitic augites, whilst there is much interstitial smoky glass. . . . The plagioclase phenocrysts are as a rule 1 to 2 mm. in size and do not exceed 3 mm. They often contain abundant inclusions of the magma sometimes arranged schiller-fashion, and are frequently eroded. Their lamellar extinctions (15° – 30°) indicate andesine labradorite. . . . The stout plagioclase lathes, which in most of my specimens range between .2 and .3 mm., and contain at times magma-inclusions, give the rocks their doleritic texture. . . . The occasional small ophitic "plates" of pale augite are not over 1 mm. in size and give extinctions of $+30^{\circ}$ from the single cleavage-lines. The lesser augites, .2 mm. in size, are several times larger than typical granular pyroxenes (.02–.03 mm.), and adapt their form to the interspaces of the felspar-lathes which they in part invest. . . . The copious interstitial glass is generally smoky and sometimes quite opaque through the deposition of magnetite. It is never clear and isotropic, but displays fibrous devitrification and is usually a little altered.

These rocks come near to those of the previous sub-genus in several respects, but they differ conspicuously in their non-porphyrific character, in being sometimes vesicular, and in their general appearance. All the four species indicated by the length of the felspar-lathes are here represented; but the doleritic types with the lathes exceeding .2 mm. are the most frequent.

10. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, oph, phen, opac.*

CHARACTERS.—In the groundmass the felspar-lathes and prisms are not in flow-arrangement and the augite is ophitic or semi-ophitic. The plagioclase phenocrysts are opaque.

This genus may be divided into two sub-genera, porphyritic and non-porphyrific, according to the average size of the plagioclase phenocrysts, whether above or below 3 mm.

A. PORPHYRITIC SUB-GENUS.—This is represented by a light grey porphyritic rock, with sp. gr. 2.75, from the lower part of Mount Freeland. It comes near to the porphyrites, and displays large opaque white phenocrysts of plagioclase 5 or 6 mm. long. It is a somewhat altered rock.

In the thin section it displays the plagioclase phenocrysts in a ground mass of doleritic and semi-ophitic texture showing a plexus of long felspar-lathes partly invested by small augites with a fair amount of altered greenish opaque interstitial glass. . . . The plagioclase phenocrysts, which give extinctions of 11° to 15° (acid andesine), are traversed by a network of fine cracks and contain a quantity of colourless dust-like inclusions and alteration-products. They are long and rectilinear in outline and are not much affected by the magma. . . . The felspar-lathes, which average .26 mm. in length, are occasionally lamellar when the angle of extinction indicates acid andesine. Like the phenocrysts they contain many dust-like inclusions. . . . The augite may at times form an aggregate phenocryst of small size ; but usually it occurs as semi-ophitic masses .1 mm. in diameter.

B. NON-PORPHYRITIC SUB-GENUS.—The specimen representing this group is a coarse-grained greyish altered rock, sp. gr. 2.81, found in blocks near Waikatakata (p. 204), showing small somewhat opaque plagioclase phenocrysts. In the section these phenocrysts are displayed in numbers together with a few of augite. The groundmass, doleritic in texture in this species, displays a plexus of long stout felspar-lathes with numerous semi-ophitic lesser augites, chloritic pseudomorphs after pyroxene, and scanty interstitial altered glass. . . . The plagioclase phenocrysts, 2 to 3 mm. in size, give extinctions (22° to 28°) of basic andesine. They are traversed by many fine cracks and contain an abundance of colourless dust-like inclusions, apparently altered magma products. . . . The small pyroxene phenocrysts consist of aggregates of smaller crystals of pale augite. The lesser augites, .1 mm. in size, partly invest the felspars. . . . The broad felspar-lathes, which average .25 mm. in length and give lamellar extinctions of medium andesine (15°), contain inclusions similar to those of the phenocrysts. . . . The scanty interstitial glass is converted into viriditic and chloritic materials. Secondary calcite also occurs here and in the chloritic pseudomorphs.

The only species represented is that with felspar-lathes .2 to .3 mm. in length.

12. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, non-flu, oph, non-phen, parv.*

CHARACTERS.—In the groundmass the felspar lathes and prisms are not in flow-arrangement and the augite is ophitic or

semi-ophitic. No plagioclase phenocrysts. Augite phenocrysts when present less than 2 mm. in size.

DESCRIPTION.—These rocks come near to the non-porphyrific group of genus 9; but differ in the absence or rarity of plagioclase phenocrysts, in their more frequently vesicular and scoriaceous character, and in the fresher condition of the rock. Their sp. gr. is about 2·77. They present themselves usually as blackish-brown doleritic rocks and form ancient flows in the coast-plains, sometimes exhibiting a columnar structure as in the crossing of the Ndreketi above Mbatiri. They are, however, of limited occurrence and are mostly represented in the Ndreketi plains and in the district between the Lekutu River and Wailea Bay.

Typically they display in thin sections no phenocrysts either of plagioclase or of pyroxene, and exhibit a plexus of usually long stout felspar-lathes partly invested by the lesser augites in a copious smoky glass. . . . The felspar-lathes, '25 to '4 mm. in length, give lamellar extinctions of 10° to 20° (andesine) and contain a few magma-inclusions. . . . The semi-ophitic augites, '1 to '2 mm. in size, are sometimes twinned. . . . The smoky glass polarises feebly and displays dark feathery aggregates of microliths. Within it are brownish-yellow semi-opaque patches of residual glass, which polarise faintly and behave like palagonite.

The two species with felspar-lathes '2 to '3 mm. and '3 to '5 mm. are represented in my collection.

4. GRANULAR SUB-ORDER OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, flu, gran.*

13. GENUS

FORMULA.—*Aug, matr, flu, gran, phen, vitr.*

CHARACTERS.—In the groundmass the felspar-lathes or prisms are in flow-arrangement and the augite is granular. The plagioclase phenocrysts are glassy.

DESCRIPTION.—This genus readily splits up into two sub-genera, the non-porphyrific, where the plagioclase phenocrysts are less than 3 mm. in size, and the porphyritic where they are larger.

1. NON-PORPHYRITIC SUB-GENUS.—Dark-brown or blackish rocks displaying small plagioclase phenocrysts, usually only 1 or 2 mm. in size. Three of the four species defined by the length of the felspar-lathes are represented in my collection.

SPECIES A.—Felspar-lathes $\cdot 02$ – $\cdot 1$ mm. in average length. This may again be sub-divided according to the degree of basicity of the rocks:—

(a) *Sub-species of greater basicity*.—Sp. gr. 2.76 to 2.82. . . . Such rocks are represented in dykes and in the prevailing basic agglomerates. They are at times scoriaceous. The small plagioclase phenocrysts, which are fairly numerous, give lamellar extinctions of andesine labradorite (20 to 30°). Two kinds occur which may or may not be represented in the same slide. In the one the crystal is much corroded and contains abundant magma-inclusions. It belongs in such a case to an earlier period. In the other the outlines are clean and regular, and the crystal is often cross-maced to such an extent that it may be inferred from its unbroken condition to have been formed *in situ*. Augite phenocrysts when present are small and scanty, pale-yellow, idiomorphic, and giving extinctions of $+30^\circ$. The felspar-lathes, which average $\cdot 06$ – $\cdot 08$ mm. in length, give extinctions indicating andesine labradorite. The augite granules are small ($\cdot 01$ – $\cdot 02$ mm.). Interstitial glass, generally scanty, is sometimes abundant when it is smoky, showing fibrous devitrification, with irregular “lacunæ” filled with a brownish yellow opaque glass like palagonite.

(b) *Sub-species of lesser basicity*.—Sp. gr. 2.65–2.70. . . . The remarks on the plagioclase phenocrysts of the more basic sub-species here apply, except that the lamellar extinctions indicate medium andesine (12° – 20°). The characters of the augite phenocrysts and granules are in both groups the same; but in this case there is more frequently a suspicion of intergrowth with rhombic pyroxene. The felspar-lathes are very small, $\cdot 04$ or $\cdot 05$ mm, and give simple extinctions of acid andesine (5 – 10°). Interstitial glass exists in moderate amount.

SPECIES B.—Felspar-lathes $\cdot 1$ – $\cdot 2$ mm. in average length.

Blackish or dark-grey rather compact rocks, sp. gr. 2.75–2.79, that cannot be readily divided into groups according to their basicity. They form dykes and volcanic “necks” and are sometimes scoriaceous. The small plagioclase phenocrysts, which are most evident in the slide, present the two kinds above described under Species A. They give lamellar extinctions varying from those of medium andesine to acid labradorite (15 – 30°). The augite phenocrysts, which are small and scanty, occasionally show intergrowths of rhombic pyroxene. The augite granules are generally $\cdot 02$ to $\cdot 03$ mm. in size, and here and there a prism form gives extinctions of $+25^\circ$. The felspar-lathes which average $\cdot 11$ to

·15 mm. long, are often rather stout, showing a few lamellæ that give extinctions of medium and basic andesine. Interstitial glass occurs in fair amount.

SPECIES C.—Felspar-lathes ·2—·3 mm. in average length.

Blackish rocks with sp. gr. 2·75—2·84. The description of Species B applies here. The plagioclase phenocrysts are for the most part microporphyritic. The size of the augite granules is as above given.

2. PORPHYRITIC SUB-GENUS.—This group of rocks is mostly confined to the slopes and vicinity of Mount Seatura in the western part of the island, being prevalent in the Mbua and Ndama plains, and occurring also as dyke-rocks in the Nandi Gorge leading into the Ndriti Basin, and at and near the coasts of Wainunu Bay between the Tongalevu and Wainunu rivers. They come near in appearance to the porphyritic forms of the blackish olivine-basalts belonging to genera 13, 25, and 37 of the olivine rocks; but they differ in the absence of that mineral, in their lower density, and in other characters. They are the type to which the term "porphyritic basaltic andesite" is most frequently applied in the text when the ophitic structure is not displayed.

They are blackish rocks having a specific gravity of 2·71 to 2·81 and exhibiting large porphyritic crystals of plagioclase, but they vary in their minute structure on account of the different size of the felspars of the groundmass. Those forming dykes in the Nandi Gorge are often more or less propylitic in character. The felspar-lathes, which have an average length of ·2 to ·3 mm., sometimes show a few lamellæ giving extinctions of medium andesine (12°—20°). The plagioclase phenocrysts of the same andesine are 3 to 5 mm. in size. They are eroded and contain abundant magma inclusions. There are a few small phenocrysts of pale brown augite. The augite granules are ·03 or ·04 mm. in diameter, and there is a little dark opaque residual glass.

The rocks of the Mbua and Ndama plains have a specific gravity of 2·81. The plagioclase phenocrysts, which yield extinctions of basic andesine (21—27°), are sometimes a centimetre in length. They are traversed by cracks filled with dark altered glass or occupied by brownish films. The felspar-lathes, which average ·11 mm. in length, are often stout and lamellar and give extinctions like the phenocrysts. Augite phenocrysts are either absent or scanty; whilst the granules average ·02—·03 mm. in size. There is usually a little interstitial glass.

A rock, almost holocrystalline and 2·74 in density, which was obtained from the Tongalevu district in Wainunu Bay, approaches the orthophyric type in the character of the ground mass. The felspars are short (·06 mm.) and stout, and yield lamellar extinctions of oligoclase (5° — 10°). The plagioclase phenocrysts are of basic andesine. Amongst the granules (·025 mm.) of pale brown augite occur prismatic forms giving oblique extinctions of $+30^{\circ}$.

14. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, flu, gran, phen, opac.*

CHARACTERS.—In the groundmass the felspar-lathes are in flow-arrangement and the augite is granular. The plagioclase phenocrysts are opaque.

DESCRIPTION.—Only two rocks are referred to this genus. One which is dark grey with a specific gravity of 2·72 is exposed in the gorge of the Mbutu-mbutu River below the falls of Na Savu. Flow-arrangement is displayed both by the felspar phenocrysts and lathes. The phenocrysts, 2 to 3 mm. in size, owe their opacity to the abundance of inclusions of brown glass. They are corroded and give extinctions of acid labradorite (26 — 32°). Pyroxene phenocrysts are scanty and small. The groundmass has a characteristic "pilotaxitic" appearance, the densely packed felspar-lathes averaging only ·05 mm. in length, whilst the pyroxene granules are ·01 mm. in size. Residual glass scanty.

The other rock is from the range behind Sueni. It shows large porphyritic crystals (5 or 6 mm.) of medium andesine which contain magma-inclusions in abundance. The average length of the felspar-lathe is ·08 mm. and the size of the augite granules is ·02 mm. There is but little glass. The rock is somewhat altered.

16. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, flu, gran, non-phen, parv.*

CHARACTERS.—In the groundmass the felspar-lathes are in flow-arrangement and the augite is granular. Plagioclase phenocrysts are absent, or if present very scanty and not usually over 1 mm. in size. When present the augite phenocrysts are under 2 mm.

DESCRIPTION.—This is a very extensive genus, admitting considerable variation and including most of the aphanitic augite-

andesites, where the felspar-lathes are as a rule very small (under $\cdot 1$ mm. in length), as well as some of the doleritic types where they are very large ($\cdot 2$ to $\cdot 4$ mm. long). In assigning a rock a place in this genus some regard must be paid to its macroscopic aspect as well as to the presence or absence of plagioclase phenocrysts. In many cases two or three small phenocrysts may be observed in a slide, under a millimetre in size; but they do not give a character to the naked-eye appearance of the rock, and such rocks cannot be distinguished from others that do not display them.

These rocks range in specific gravity from 2.55 to 2.85. This large range is in the main concerned with different degrees of basicity depending on the character of the plagioclase, the relative abundance of the augite granules, &c.; but it is also connected with the amount of interstitial glass. The variety of plagioclase ranges between oligoclase and andesine labradorite. The fluidal structure is nearly always well-marked, and the closely packed felspar-lathes have often the peculiar "felted" appearance of many andesites. A little interstitial glass is present in most rocks.

Many, perhaps nearly all, of the rocks belong either to dykes or to larger intrusive masses. All the four species indicated by the length of the felspar-lathes are represented in my collection, especially the two with smallest felspars. They may again be split up into two sub-species according to the degree of basicity of the rocks.

SPECIES A.—Felspar-lathes between $\cdot 02$ mm. and $\cdot 1$ mm. in average length.

(1) *Most basic sub-species* . . . Sp. gr. 2.75–2.85. Dark-brown and dark-grey compact aphanitic rocks showing no plagioclase phenocrysts to the eye. When a few of these phenocrysts are present in a slide they are not usually much over 1 mm. in size, and give extinctions of andesine labradorite (20° to 30°). Augite phenocrysts are often absent, and when present are not over 1 mm. in size and are as a rule scanty, occasionally affording a suspicion of inter-growths with rhombic pyroxene. The felspar-lathes which display marked flow-structure, vary in average length in different rocks from $\cdot 05$ — $\cdot 08$ mm. Lamellar twinning is rare, the extinctions being those of oligoclase andesine (10° to 20°). The usual extinction, as measured from the long axis of the lathe, is 10° to 15° (medium andesine). The augite granules are small ($\cdot 01$ — $\cdot 02$ mm.) and abundant. There is generally a little interstitial glass with small magnetite.

(2) *Least basic sub-species* . . . Sp. gr. 2·55—2·75. Dark compact aphanitic rocks especially characteristic of the Ndrawa district. When plagioclase phenocrysts are present, they are very scanty and not generally over a millimetre in size, possessing rectangular clean outlines and showing but few inclusions. They may display carlsbad twinning and zoning, or albite twinning, when they give extinctions of oligoclase andesine (10° — 15°). Pyroxene phenocrysts are either absent, or scanty and small, being usually of pale yellow augite with occasional indications of intergrowth with rhombic pyroxene. The felspar-lathes as a rule average ·07 or ·08 mm. and present a dense fluidal arrangement. They rarely display lamellar twinning and give extinctions measured from the long axis of oligoclase and oligoclase andesine (2° — 8°). The pyroxene granules are very small, averaging ·01 mm. and less. There is also fine magnetite. A little interstitial glass is usually present. When abundant it is not generally smoky but shows clear fibrous devitrification. . . . One of the specimens, which is semi-vitreous, exhibits tube-like steam-pores drawn out to a length of 1—1½ centimetres. The felspar microliths are only ·02 mm. in length. The copious glass has the character above described.

SPECIES B.—Felspar-lathes ·1—·2 mm. in average length.

This species may also be sub-divided into two sub-species (more basic and less basic). Since, however, all but one of the fifteen rocks belonging to the species are of the more basic kind my remarks will mainly apply to them. They are dark-brown or dark-grey compact aphanitic rocks, occasionally banded or streaky, in appearance, and ranging in specific gravity from 2·75 to 2·84. They occur in several districts, but are especially characteristic of the Ndrawa district. The plagioclase phenocrysts, if present, are very scanty and small (1 or 1½ mm.). They contain inclusions of the magma and give lamellar extinctions of andesine labradorite (20° — 30°). Pyroxene phenocrysts do not generally occur. When present, they are small and of pale yellow augite yielding large extinctions. Occasionally micro-porphyrific augite is well represented. The felspar-lathes, which exhibit a well-marked flow-arrangement, are generally ·13 to ·15 mm. long. Lamellar twinning is uncommon, the extinctions measured from the long axis indicating basic andesine (10° — 20°). The augite granules are abundant and small (·01—·02 mm.). Occasional prism-forms yield large extinctions. Magnetite is abundant, its grains corresponding in size to the augite granules. There is as a rule a little residual glass, which shows fibrous devitrification and is not smoky. The

banded appearance of some of the rocks arises from the glass collecting in streaks rudely parallel and running in the direction of the "flow" of the felspar-lathes.

The only specimen in my collection of "sliced" rocks belonging to the less basic sub-species is an altered bluish-grey rock (sp. gr. 2·7) from the range between the Mbuthai-sau valley and the Wainikoro plains. Its long parallel untwinned felspar-lathes give the nearly straight extinctions of oligoclase. Fine cracks in the rock are filled with crystalline silica.

SPECIES C, felspar-lathes ·2—·3 mm. long.

SPECIES D, " " ·3—·5 " "

The rocks of these species in the collection are for the most part dyke-rocks of the more basic kind. They are blackish or dark-brown, almost doleritic in texture, and range in specific gravity from 2·77 to 2·87. At times they are vesicular or scoriaceous, as in the specimens from an agglomerate at Undu Point and from a flow or dyke at Vunikondi. The most typical of these rocks are those of some of the dykes of the Ndriti basin, which, however, display propylitic alteration in a varying degree. They would be described as semi-doleritic basalts without olivine or as non-porphyrific basaltic andesites. Plagioclase phenocrysts are typically absent, or they are scanty and not over 1 mm. in size. Augite phenocrysts are usually scanty and small. The felspar-lathes, which are more or less in flow-arrangement, are rather stout, and range in average length in different rocks from ·23 to ·35 mm. They often show a few twin-lamellæ which yield extinctions of medium and basic andesine (15—28°). The augite granules are large (·03 mm.) in the Ndriti rocks. Magnetites, usually corresponding in size to the augite granules, are abundant. Interstitial glass occurs often in fair quantity and is dark and semi-opaque.

At times there can be recognised a later generation of minute felspar microliths between the much larger lathes. They display a plexus rather than a flow-arrangement. Whilst the larger parallel lathes of the Vunikondi rock, above referred to, average ·23 mm. long, the felspar microliths of the interspaces average only ·03 mm. The significance of these two crops of felspars in the groundmass is discussed on page 237.

The only rock of the less basic sub-species in my collection is from a dyke near Vatua-karoa. It shows secondary calcite and viridite and other evidences of the propylitic change. The felspar-lathes, which average ·3 mm. in length, give extinctions of oligoclase (0—5°). The specific gravity is 2·72.

5. SUB-ORDER, PRISMATIC, OF THE AUGITE-ANDESITES

(Felspar-lathes in flow-arrangement. *Aug, matr, flu, prism.*)

This sub-order includes dark-brown or blackish semi-vitreous rocks, all but one of which belong to the genus below described. Since the exception (which belongs to genus 17 of the synopsis) differs only in the presence of plagioclase phenocrysts, its separate description is not needed.

20. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, flu, prism, non-phen, parv.*

CHARACTERS.—In the groundmass the felspar-lathes are in flow-arrangement, and the augite is prismatic. Plagioclase phenocrysts are absent or are very small and scanty, and pyroxene phenocrysts when present do not exceed 2 mm. in size.

DESCRIPTION.—These dark semi-vitreous rocks occur in agglomerates and as "necks" and dykes, and are at times scoriaeous. They are usually compact and aphanitic, showing few if any plagioclase phenocrysts and having a semi-conchoidal fracture. The specific gravity varies, being generally 2·6—2·65, but according to the degree of basicity and amount of glass it may be as low as 2·5 or as high as 2·77. In the less glassy condition, as in the case of a rock from the ridge east of Na Raro, the felspar-lathes are relatively scanty and the groundmass is mainly formed of augite prisms in flow-arrangement. The lathes are generally small, less than ·1 mm., and rarely over ·2 mm. Their extinctions are those of oligoclase and acid andesine. The pyroxene prisms, which give the large extinctions of augite, have a pale muddy-brown hue and are as a rule ·03—·07 mm. long. Granular pyroxene, if present, is subordinate in amount. The glass, which is always in good quantity and is sometimes abundant, displays fibrous devitrification. In a rock from the vicinity of Narengali a variolitic structure is exhibited in the form of sheaf-like aggregates of fibre-like felspars and skeleton prisms of pyroxene.

6. SUB-ORDER, OPHITIC, OF THE AUGITE-ANDESITES

(Felspar-lathes in flow-arrangement. *Aug, matr, flu, oph.*)

21. GENUS OF THE AUGITE-ANDESITES

FORMULA.—*Aug, matr, flu, oph, phen, vitr.*

CHARACTERS.—In the groundmass the felspar-lathes are in

flow-arrangement and the augite is ophitic or semi-ophitic. Glassy plagioclase phenocrysts.

DESCRIPTION.—Dark rocks, sp. gr. 2·76—2·8, forming ancient flows and displaying at times a columnar structure as at Yanutha Point (page 123). The ophitic character is only in part developed, which may be connected with the flow-arrangement of the felspars. These rocks come near to the blackish ophitic basalts with scanty olivine (genus 33 of the olivine sub-class).

They all belong to the non-porphyrific sub-genus where the plagioclase phenocrysts are less than 3 mm. in size. These phenocrysts, which often contain abundant magma-inclusions, give extinctions of andesine labradorite (20° — 30°). The augite phenocrysts are small and composite in character as often happens with these ophitic rocks. They sometimes invest the smallest felspar phenocrysts, and occasionally display intergrowths of rhombic pyroxene. The felspar lathes are ·1 to ·14 mm. in length, and give extinctions of medium and basic andesine. The augite granules are large (·02—·06 mm.), and tend to wrap around the lathes. Interstitial glass exists in fair amount.

CHAPTER XX

THE VOLCANIC ROCKS OF VANUA LEVU (*continued*)

HYPERSTHENE-AUGITE CLASS

II. SUB-CLASS. HYPERSTHENE-AUGITE-ANDESITES

FORMULA.—*Plag, hypersth-aug, matr.*

CHARACTERS.—The pyroxene phenocrysts usually are represented by separate crystals of the monoclinic as well as the rhombic type, and the two forms are often associated in the same crystal. The monoclinic form prevails in the groundmass in most cases.

REMARKS.—It is not possible to draw a sharp line between the augite and the hypersthene-augite-andesites ; but where two or three phenocrysts of the rhombic type occur in a slide the rock may be placed in this division. Between this variety and that where rhombic pyroxene prevails, both among the phenocrysts and in the groundmass, numerous intermediate kinds exist. These rocks mostly occur in agglomerates and form small and large dykes or sills, but rarely are found in flows. They are distributed over most of the island except in the western portion (the basaltic districts of Wainunu, Seatura, and Solevu), but reappear again in the Mbua peninsula in places, as at Mount Koroma.

The pale yellow rhombic pyroxene is uniform in its optical behaviour. The prisms are noticeably pleochroic, being nearly colourless when lying across the long axis of the lower nicol and pale yellow when parallel with it. The intergrowths with monoclinic pyroxene often take the form of lamellar bands, whilst in some cases a nucleus of the one (usually rhombic) is invested by a growth of the other.

I. SUB-ORDER, GRANULAR, OF THE HYPERSTHENE-AUGITE-ANDESITES

*(Felspar-lathes not in flow-arrangement.)*FORMULA.—*Hypersth-aug, matr, non-flu, gran.*

1	genus . . .	(<i>Vitr.</i>)	} See Synopsis, p. 247.
2	" . . .	(<i>Opac.</i>)	
3	" . . .	(<i>Magn.</i>)	
4	" . . .	(<i>Parv.</i>)	

Nearly all of the rocks of this sub-order that are represented in my collection belong to the genus (1) with phenocrysts of glassy plagioclase. They vary considerably in appearance and in colour (black to grey), and occur under very different conditions, as in "necks," old flows, large intrusive masses, dykes, agglomerates, &c. Their specific gravity has rather a wide range according to the degree of basicity. In the heavier rocks where the rhombic pyroxene is scanty, it is usually 2·7 to 2·8. In the others, where rhombic pyroxene is more predominant and where the felspar is less basic, it is 2·6 to 2·7.

In the slide small phenocrysts of plagioclase and pyroxene occur in a groundmass of felspar-lathes and pyroxene granules, whilst there is as a rule a fair amount of residual glass. The plagioclase phenocrysts, which give extinctions in different rocks of acid and basic andesine and contain abundant magma-inclusions, are generally one to two mm. in size. The pyroxene phenocrysts are small, and may be represented by separate crystals of the monoclinic and rhombic kinds, or by crystals displaying intergrowths of the two sorts. The pyroxene granules vary much in size and are evidently in great part of augite. In most of the rocks the felspar-lathes are less than 1 mm. in length. In those where the length is 1 to 2 mm. they are sometimes stout and display a few lamellæ, yielding extinctions corresponding to those of the phenocrysts.

A singular dark grey almost holocrystalline doleritic rock (sp. gr. 2·85) is exposed in the Thulanga Ridge (p. 211). It shows no plagioclase phenocrysts, but those of pyroxene are numerous, which, however, do not exceed 2 mm. in size, so that the rock would be referred to genus 4 of this sub-order. It appears to be a doleritic form of the plutonic rock found at Nawi in this neighbourhood (p. 211). The pyroxene phenocrysts are mostly of brownish-yellow augite, but rhombic pyroxene, either as separate crystals or as intergrowths, is not uncommon. The plagioclase lathes are long

and fairly stout, giving at times lamellar extinctions of 20° . Their average length is $\cdot 3$ mm., and it is to their large size that the doleritic texture is due. The pyroxenes of the groundmass are similarly coarse ($\cdot 2$ mm.), and include both monoclinic and rhombic forms, the latter infrequent. There is a slight tendency to semi-ophitic behaviour in places; but generally these pyroxenes are irregular in shape or rudely prismatic.

2. SUB-ORDER, PRISMATIC, OF THE HYPERSTHENE-AUGITE-ANDESITES

(*Felspar-lathes not in flow-arrangement.*)

FORMULA.—*Hypersth-aug, matr, non-flu, prism.*

5	genus . . .	(<i>Vitr.</i>)	} See Synopsis.
6	" . . .	(<i>Opac.</i>)	
7	" . . .	(<i>Magn.</i>)	
8	" . . .	(<i>Parv.</i>)	

This sub-order includes rocks varying much in appearance, but all alike in the presence of prismatic pyroxene in the groundmass and in the absence of flow-arrangement of the felspar-lathes. They belong to the two genera, with glassy and opaque plagioclase phenocrysts. These crystals are not usually over 2 mm. in size and are of medium andesine (15° — 20°). The pyroxene phenocrysts are small and may be entirely of monoclinic or of rhombic pyroxene, or the two may be associated either as lamellar intergrowths, or by displaying an eroded nucleus (generally rhombic) around which a regular crystal of monoclinic pyroxene has grown. The felspar-lathes are in some cases less than $\cdot 1$ mm. long, and in others $\cdot 1$ — $\cdot 2$ mm. The pyroxene prisms of the groundmass average $\cdot 01$ — $\cdot 04$ mm. in length, and give both straight and oblique extinctions, the last prevailing. The specific gravity ranges from $2\cdot 55$ to $2\cdot 75$ according to the degree of basicity and amount of interstitial glass, which is usually in fair quantity.

4. SUB-ORDER, GRANULAR, OF THE HYPERSTHENE-AUGITE-ANDESITES

(*Felspar-lathes in flow-arrangement.*)

13. GENUS

FORMULA.—*Hypersth-aug, matr, flu, gran, phen, vitr.*

CHARACTERS.—Glassy plagioclase phenocrysts.

DESCRIPTION.—This is a group of rocks that comes near the basaltic andesites represented in genera 1 and 13 of the augite sub-class; and to the more basic kinds the terms of basaltic andesite is equally applicable. These rocks, however, differ in the prevalence of rhombic pyroxene, which occurs as phenocrysts, but always accompanied by monoclinic pyroxene, whether as separate crystals or as inter-growths. Such rocks are intermediate between those of the augite and rhombic pyroxene classes. They are particularly characteristic of the Savu-savu peninsula, but they are also found in other scattered localities. Sometimes they appear to form ancient flows, and at other times intrusive masses and dykes; but they are rarely scoriaceous.

Almost all the rocks in my collection referred to this genus belong to the species where the felspar-lathes of the groundmass are .02—.1 mm. long. They are generally blackish or dark-brown, and the specific gravity ranges usually from 2.72 to 2.83. They display in the slide a fair number of plagioclase and pyroxene phenocrysts in a groundmass of felspar-lathes, pyroxene granules, and magnetite, the interstitial glass being scanty or moderate in amount. . . The plagioclase phenocrysts are rarely as large as 3 mm., so that most of the rocks belong to the non-porphyrific group of the genus. These phenocrysts, which are often zoned, give extinctions of basic andesine (15°—25°). They contain magma-inclusions, sometimes in abundance, which are arranged in zone-lines. . . The pyroxene phenocrysts are small, the two kinds being always represented in the same slide. In some cases separate crystals occur, and in others the two are associated as intergrowths, but in most cases separate and compound crystals occur in the same section. Not infrequently the phenocryst is an aggregate of lesser crystals of the two pyroxenes. The monoclinic form is a brownish yellow augite with large extinctions and often twinned. The felspar-lathes of the groundmass, which usually average .05 or .06 mm. in length, are either narrow and untwinned, or they may be stouter and display simple and at times lamellar twinning, giving extinctions of medium andesine. . . The granules of pyroxene are generally .01—.02 mm. in size; but occasional prism-forms occur which give sometimes the straight extinction of rhombic pyroxene and at other times the large oblique extinctions of the augite type.

5. SUB-ORDER, PRISMATIC, OF THE HYPERSTHENE-AUGITE-ANDESITES

(*Felspar-lathes in flow-arrangement*)

FORMULA.—*Hypersth-aug, matr, flu, prism.*

17	genus . . .	(<i>Vitr.</i>)	} See Synopsis.
18	„ . . .	(<i>Opac.</i>)	
19	„ . . .	(<i>Magn.</i>)	
20	„ . . .	(<i>Parv.</i>)	

The rocks of this sub-order that are represented in my collection admit easily of a general description, and since the diagnoses of the genera are given in the Synopsis, there will be no need to separately describe each genus.

Almost without exception these rocks form a constituent of agglomerates in various parts of the island; and they occur in this condition in some of the highest mountains, as Mariko, Thambeyu, and Koro-mbasanga. The exception refers to a low mound-like hill, apparently a “volcanic neck,” that rises from the basaltic plains west of Mbua (see page 58).

In about half of the specimens the rocks are referred to section 10, where the plagioclase phenocrysts are either small and very scanty or are absent altogether. In a fair number these phenocrysts are opaque (genus 18); whilst in a few they are glassy (genus 17). The rocks are typically blackish or dark grey, and often have a pitchstone-like appearance, the groundmass being frequently semi-vitreous in character. Vesicular and scoriaceous rocks occur at times.

In all cases the felspar-lathes and pyroxene prisms are more or less in flow-arrangement; whilst pyroxene granules, if present, are subordinate. The felspar-lathes, which are either simple or once-twinned and give extinctions of acid and medium andesine, are usually small, and average in different sections .05—.08 mm. in length. The pyroxene prisms are pale brown and are .03 or .04 mm. long. Most of them give oblique extinctions of over 25°; but in the same slide some give straight extinctions; the proportion varies in different rocks. The pyroxene phenocrysts in all the specimens are small (not over 2 mm.), and are rhombic and monoclinic. In most sections the two forms are represented by separate crystals and are also associated in the same phenocryst. Those of rhombic pyroxene have often dark borders. There is a considerable amount of a pale brown glass in the groundmass,

more or less devitrified. The specific gravity varies considerably, but is as a rule between 2·55 and 2·75, the more basic rocks containing augite in preponderance and basic andesine, whilst the less basic possess a large proportion of rhombic pyroxene and display oligoclase-andesine. Sometimes, as in the case of a rock composing an agglomerate east of Nanduri, where the porphyritic plagioclase is opaque and there is some degree of alteration, the rock looks very like a porphyrite.

THIRD ORDER, ORTHOPHYRIC, OF THE HYPERSTHENE-AUGITE-ANDESITES

FORMULA.—*Hypersth-aug, matr, orth.*

CHARACTERS.—Felspars of the groundmass short and broad.

Since the material is insufficient for the separate description of each genus, a general account of the order is alone given. These rocks are often represented in agglomerates or they occur as large blocks, either lying on the surface or imbedded in tuffs. Many of them are somewhat altered.

They are for the most part dark grey dull-looking rocks, with a specific gravity of 2·7 to 2·8, showing macroscopic plagioclase together with conspicuous pyroxene phenocrysts. The plagioclase phenocrysts are usually small (1 to 3 mm.), and give extinctions of medium andesine (15°—20°) and in some rocks of acid labradorite (30°). They are as a rule corroded and are penetrated by numerous fissures, whilst they contain a considerable amount of altered magma-inclusions with sometimes other alteration products. The pyroxene phenocrysts are from 2 to 4 mm. in size. Brownish-yellow augite, giving extinctions of over 30°, and pale-yellow rhombic pyroxene of the type before described occur generally in the same slide, and are frequently associated as intergrowths in the same crystal. They may have regular outlines or dark eroded borders, and at times they exhibit abundant dark opaque inclusions. The broad felspars of the groundmass are sometimes rectangular and give lamellar extinctions of medium and acid andesine (12°—17°). They vary in length in different rocks from ·05 to ·2 mm. and more. The pyroxene of the groundmass is generally granular and coarse (·02—·05 mm.). As indicated by the extinctions of occasional prism-forms it is composed of both augite and rhombic pyroxene, the former prevailing. The prismatic sub-order is also represented, and here the pyroxene of the groundmass is in great part prismatic, the length of the prisms

not often exceeding .05 mm., whilst both the monoclinic and rhombic kinds occur. Interstitial glass varies in amount, sometimes absent, sometimes scanty and viriditic, at other times abundant and opaque. Magnetite abounds in the groundmass much of it often being of secondary origin.

FOURTH ORDER, FELSITIC, OF THE HYPERSTHENE-AUGITE ANDESITES

FORMULA.—*Hypersth-aug, matr, fels.*

CHARACTERS.—The groundmass presents a rudely granular appearance or a blurred mosaic.

This order is capable of subdivision, as in the other orders of the hypersthene-augite-andesites (see Synopsis, page 247); but since it is only represented by six of my rock-sections, I will confine the description to the general characters.

These rocks are dark-grey, sometimes granitoid in appearance, with specific gravity 2.65 to 2.75. They usually show some alteration, arising from secondary changes within the rock-mass; and probably the felsitic or semi-mosaic appearance of the scanty groundmass is the result of such a secondary change. Such rocks in some respects approach the type of the gabbros. They are frequent on the north coast of Natewa Bay in the vicinity of Waimotu and also occur in the Valanga Ridge. They generally present themselves as deeper-seated massive rocks exposed by the stripping off of the superficial deposits.

There are as a rule more or less conspicuous phenocrysts, up to 3 mm. in size, of plagioclase and pyroxene, in a relatively scanty micro-felsitic groundmass, displaying a blurred mosaic, in which a few stout felspar-lathes can still be recognised, and composed apparently of felspar and crystalline silica. The "grain" of the mosaic may range in different rocks from .005 mm. to .02 mm. The pyroxene of the groundmass is largely decomposed, and the scanty residual glass is represented by viriditic materials.

The plagioclase phenocrysts, which give extinctions of medium and basic andesine (15° — 25°), are often semi-opaque and corroded. They are traversed by numerous cracks and often contain many whitish alteration products, though the lamellar structure is usually well preserved. The pyroxene phenocrysts are composed of brownish-yellow augite (ext. + 30°) and pale rhombic pyroxene

of the type described before, either as separate crystals or associated as intergrowths. The rhombic pyroxene crystals are often sub-rounded with dark borders; and as a rule the pyroxene phenocrysts are much fresher than the plagioclase phenocrysts. As far as can be ascertained, most of the original pyroxene of the groundmass was monoclinic with a little rhombic.

CHAPTER XXI

THE VOLCANIC ROCKS OF VANUA LEVU (*continued*)

ACID ANDESITES

Previous observations on the Hornblende-Andesites of Fiji

THESE rocks were first described by Wichmann¹ from specimens obtained by Kleinschmidt from the mountain of Mbuke Levu in Kandavu. These Kandavu rocks had a microfelsitic base, the porphyritic brown hornblende having usually black borders in which a change into epidote was observed. Rhombic pyroxene was only noted as an occasional constituent of a rock from Ono. Renard² described these rocks from the vicinity of Ngaloa Harbour in Kandavu and remarked that bronzite was of more common occurrence than the monoclinic pyroxene. In the ground-mass were numerous felspar and augite microliths, whilst there was a porphyritic development of plagioclase, hornblende, biotite, and pyroxene. The hornblende phenocrysts played an important part in the rock-composition, being surrounded by a black zone of magnetite or bordered by a bacillary aggregate of small pyroxene prisms, parallel and colourless or greenish, with extinction-angles of 90° . There was often also a development of biotite in the heart of the mineral, the whole hornblende section being sometimes thus transformed.

Mr. Eakle³ has more recently described the hornblende-andesites from Mbuke Levu in Kandavu. As the result of his examination of a collection of volcanic rocks made by the Agassiz expedition in

¹ *Petrographie des Viti Archipels*; Miner. und Petrogr. Mittheil; band v, Heft 1, Wien, 1882.

² *Physics and Chemistry*, II. Report Scient. Results; H.M.S. *Challenger*; London, 1889.

³ *Petrographical Notes on the Fiji Islands*; Proceed. Amer. Acad. Arts and Sciences; vol. 34; no. 21; May, 1899.

Viti Levu, Kandavu, Mbenga, Totoya, Malolo, Yasawa group, and in several other small islands, he inferred that the hornblende-andesites are much more limited in their occurrence in Fiji than the augite-andesites ; whilst hypersthene-andesite was only represented in the collection from Vomo-lailai near Waia in the Yasawas. The specimens from Waia had a microfelsitic base with pseudomorphs of hornblende and some augite. Mr. E. C. Andrews¹ in his account of his collection of volcanic rocks, made mostly in the Lau Group and Taviuni, makes no special reference to hornblende-andesites, the andesites being mainly augitic, rhombic pyroxene also occurring as a common porphyritic constituent.

It may be inferred from the above and from my own observations in Vanua Levu below given that hornblende-andesites have a relatively limited distribution in Fiji. They are not generally distributed as in the case of the augitic and basaltic andesites ; but are confined to certain localities in Viti Levu,² Vanua Levu, Ovalau, Kandavu, Ono, Malolo, Yasawa Islands, etc.

The occurrence of quartz-andesites or dacites in Fiji.—In connection with the existence of these rocks in Vanua Levu, it is noteworthy that except in Mr. Eakle's paper there is no reference in any of these writings to the occurrence of quartz-andesites in Fiji. Wichmann expressly states that the rocks he examined were free from quartz, and that up to his time (1882) no quartz-bearing younger eruptive rocks were known from the South Seas. Mr. Eakle in 1899 described a holo-crystalline andesite with a felsitic aspect from Malolo and another similar looking rock from Vatu Mbulo, in the same sub-group of the Fijian Islands, showing quartz both in the phenocrysts and in the microcrystalline groundmass, concerning which he observed that it was perhaps more of a dacite than an andesite. Dacites were found by me in 1884 in the island of Fauro in the Solomon group,³ and it is probable that they are of more frequent occurrence in the Pacific than has been generally supposed. As shown immediately below, they are represented in Vanua Levu ; and the extent of their distribution in the island depends on the limits we assign to the definition of the term "dacite."

¹ *Notes on the Limestones and General Geology of the Fiji Islands*, Bull. Mus. Comp. Zool., vol. 5. Geolog. Ser. vol 5, no. 1, Cambridge, Mass., U.S.A. Nov. 1900.

² Wichmann describes rocks from the cliffs of the Singatoka river and from Ovalau.

³ *Geology of the Solomon Islands*, by H. B. Guppy, 1887, pp. 6, 36.

If we restrict the term to a hornblende-andesite carrying porphyritic quartz and displaying a microfelsitic groundmass, such rocks, though they form some of the highest peaks in the Ndrandramea district, namely Ngaingai and Wawa-levu, would not be very frequent in Vanua Levu. If, however, a microfelsitic groundmass is alone necessary to constitute a "dacite," the great majority of the acid andesites of the island would fall under this designation.¹ This has long been a controverted point in petrology. If I adopted the last procedure, my general classification for the andesites would fall into confusion and many rocks without any quartz would be included in the dacites.

In the Synopsis it will be seen that my classification of the andesites is as far as concerns the great groups based on the mineral and not on the structural characters. There are three sub-classes closely allied to each other, the hypersthene-andesites, the hornblende-hypersthene-andesites, and the quartz-hornblende-hypersthene-andesites or dacites, which cannot be distinguished at their boundaries by their petrological characters or by their different modes of occurrence. These groups of rocks which include all the acid andesites of the island will now be dealt with.

THE ACID-ANDESITES OF VANUA LEVU

(Comprising the hypersthene-andesites ; hornblende-hypersthene-andesites ; and quartz-hornblende-hypersthene-andesites or dacites)

These rocks compose in mass numerous isolated hills that rise up abruptly in the interior of the central portion of the island. Such hills, or mountains, as they might be often termed, usually attain a height of from 700 to 1200 feet above the surrounding country, and possess precipitous slopes and frequently perpendicular cliff-faces. In the geological description of the island, I have referred in detail to these mountains, when speaking of Na Raro, Vatu Kaisia, Ndrandramea, Ngaingai, etc.; and illustrations of some of them are included in this work. It may, however, be here remarked that they are as a rule rudely conical with rounded or peaked summits. The ground-plan is generally elliptical in outline; and in consequence the profile often varies from different points of view, so that as in the case of Na Raro, it is that of a sharp conical peak when the mountain is viewed "end-on," or of a broad trun-

¹ The term "felsitic andesite" is suitable for this microfelsitic type.

cated mass when seen from the side. A similar change of form is to be noticed in the illustrations of Ndrandramea. No traces of crateral cavities came under my notice. The rocks are neither vesicular nor scoriaceous, and are usually massive ; but exhibit at times a rudely columnar structure.

Each hill or mountain has its peculiar variety of these rocks, This is well shown in the Ndrandramea district. Thus the rocks of Ngaingai and of Wawa-levu in carrying porphyritic quartz differ from those of all the other hills around. Those of Soloa Levu are distinguished by the orthophyric groundmass and by the absence of hornblende. Those of Mount Ndrandramea again have no porphyritic quartz, but little hornblende, and possess a microfelsitic groundmass. The rocks of Na Raro and Vatu Kaisia differ as regards specific gravity, the "grain" of the felsitic groundmass, the presence of phenocrysts of rhombic pyroxene, etc. The characters of these rocks from various localities are contrasted in the table given on a later page, whilst the different sub-classes to which they belong are described in detail below.

SUB-CLASS HYPERSTHENE-ANDESITES

These are dark and light grey rocks, sometimes granitoid in appearance. They pass on the one hand into the hypersthene-augite-andesites before described and on the other into the hornblende hypersthene-andesites to be subsequently dealt with. From the former they are distinguished by the great predominance of rhombic pyroxene both as phenocrysts and in the groundmass ; whilst from the latter they are separated by the absence of brown hornblende or its pseudomorphs. These rocks are found in the Ndrandramea, Valanga, and Vunimbua districts. They may form isolated dome-shaped hills as in that of Soloa Levu, or they may constitute the deeper-seated rocks of the region from which these hills arise, as in the Ndrandramea district. In their general mode of occurrence, however, they cannot be treated apart from the allied hornblende-hypersthene-andesites and the dacites.

This sub-class may be divided like the hypersthene-augite-andesites into four orders according to the character of the groundmass ; and these are enumerated in the Synopsis. Only the orthophyric and felsitic orders are represented in my collection. Of the former the most typical rocks are those composing the hill of Soloa Levu which is described on page 103.

These Soloa Levu rocks are lightish grey and granitoid in aspect,

with specific gravity of 2·54—2·62, and displaying abundant porphyritic crystals of pyroxene, 2—3 mm. in size. In the slides they show a large number of plagioclase phenocrysts together with those of pyroxene in a relatively scanty groundmass, for the most part orthophyric in texture and without residual glass. . . . The plagioclase phenocrysts, which are not usually over 2 or 3 mm. in size, are often tabular and show distinct zone-lines. Though they are traversed by minute cracks and have frequently a semi-saussuritic appearance arising partly from change-products and partly from the abundance of colourless inclusions, they yield clear lamellar extinctions of medium and basic andesine (15° — 25°). . . . The pyroxene phenocrysts, which are not much altered, are in most cases long pale-yellow rhombic prisms with rounded ends, behaving optically as described on page 285 ; but intergrowths with monoclinic pyroxene may occur and even separate crystals of augite. . . . The scanty groundmass, though in the main formed of short and broad feldspars, 12 mm. long, of the orthophyric type, displays in places a rude mosaic, apparently of quartz and feldspar. It also shows abundant small pyroxenes in the form of small prisms (0·5 mm. in length), giving extinctions nearly always straight but occasionally oblique (30° — 35°).

As examples of the felsitic order of these rocks, most of which are altered like the propylites, I will first take the case of those deep-seated rocks that are exposed in the river-bed above Nam-buna in the Ndrandramea district. In the least altered state they are dark grey and mottled, and have a specific gravity of 2·66—2·69. In section they display tabular zoned plagioclase phenocrysts, usually more or less occupied by alteration products, but at times giving lamellar extinctions of basic andesine (20° — 25°). The rhombic pyroxene is more or less replaced by chloritoid pseudomorphs ; whilst the "grain" of the mosaic is often coarse (0·3 mm.), and much of it is evidently quartz. The more advanced stages of alteration of these rocks are described in the account of the district given on page 106. . . . Similar rocks, showing pyrites, occur amongst the blocks of Vunimbua River ; but here the rhombic pyroxene is mostly converted into bastite, and the groundmass is in part trachytic as well as felsitic in texture. The specific gravity is 2·7.

(In the last survey of my collection I have found a solitary specimen from an agglomerate in the Mbua-Lekutu "divide," which must be referred to the order with feldspar-lathes in flow-arrangement. It is a pale grey rock showing abundant macro-

scopic pyroxene prisms, 2 mm. long, mostly rhombic but showing also intergrowths with monoclinic pyroxene. The felspar-lathes do not average more than .1 mm., and there is a quantity of small prisms of rhombic pyroxene in the groundmass, which also contains a little residual glass.)

SUB-CLASS HORNBLENDE-HYPERSTHENE-ANDESITES

This is an extensive group which includes the rocks forming several of the hills in the Ndrandramea district as well as the isolated peaks of Na Raro, Vatu Kaisia, etc. It passes on the one side into the Hypersthene-Andesites before described and on the other into the Hornblende-Hypersthene-Quartz-Andesites, the Dacites of this island.

Of the four orders established in the Synopsis (page 236) according to the general method there adopted, the first, where the groundmass exhibits felspar-lathes not in flow-arrangement, is not represented in my collection.

SECOND ORDER OF THE HORNBLENDE-HYPERSTHENE-ANDESITES

(Felspar-lathes in flow-arrangement)

This order is only represented by three rocks, all of which belong to the prismatic sub-order where the pyroxene of the groundmass is prismatic and not granular.

Two of these rocks are very similar in appearance and character, though coming from different localities on the opposite sides of Savu-savu Bay, one from the agglomerate of Vatu-ndamu in the Kumbulau peninsula (page 91), the other from an intrusive mass in the vicinity of Urata (page 184). They are dark grey, with specific gravity 2.6 to 2.7, and display macroscopic crystals of hornblende and pyroxene. In the slide they exhibit in addition numerous phenocrysts of plagioclase, 1 to 2 mm. in size, in a groundmass showing small felspar-lathes (less than .1 mm. in length) in partial flow-arrangement and numerous pyroxene prisms (.05 mm. long) giving straight extinctions, together with a little residual glass. . . . The plagioclase phenocrysts, which give extinctions of medium and basic andesine, are often tabular and display zone-lines. They contain abundant pale inclusions arranged zone-wise. . . . The hornblende phenocrysts are dark brown, markedly pleochroic, and give extinctions up to 12 degrees.

They have dark resorption borders and are sometimes deeply corroded. They show in various stages the remarkable conversion at the borders into fine pyroxene, which is described on page 306 The pyroxene phenocrysts are more numerous in the Urata rock. They are for the most part of the pale yellow feebly pleochroic rhombic type that prevails in the island. A few phenocrysts of pale augite (ext. 35°) may occur in the same slide ; whilst the two pyroxenes may be associated as intergrowths.

A crypto-crystalline variety of these rocks, where the felspar-lathes and rhombic pyroxene prisms of the groundmass are only in part differentiated, is found on the hills of Ndreke-ni-wai on the shores of Natewa Bay (page 201). It is a pale-grey open-textured rock, displaying numerous small macroscopic crystals of hornblende.

THIRD ORDER OF THE HORNBLLENDE-HYPERSTHENE-ANDESITES

(Felspars of the groundmass, short and broad, of the orthophyric type)

These rocks occur generally as agglomerates and are more particularly characteristic of the district between the Mariko Range and the Salt Lake. They belong for the most part to the prismatic sub-order of the group and to the section with plagioclase phenocrysts, and fall naturally into two divisions corresponding to the two genera with *glassy* and *opaque* phenocrysts. The last named would be regarded by some as porphyrites. The specific gravity of the specimens ranges from 2.52 to 2.7.

The plagioclase phenocrysts, 1 to 2 mm. in size, give extinctions indicating in some rocks oligoclase-andesine (10° — 15°) and in others basic andesine (15° — 25°). Their opacity in the porphyrites is sometimes due to multiple macting, but more usually it arises from the numerous fine cracks filled with decomposition products that traverse them. The phenocrysts of dark brown hornblende are generally abundant and give extinctions of 15 degrees. They as a rule have dark resorption borders in which the process of conversion into fine pyroxene is in active operation. The pyroxene phenocrysts are scanty and in most cases rhombic ; but intergrowths with augite and separate crystals of the last-named may occur. In the altered rocks or porphyrites they are largely replaced by bastite and viridite. The felspars of the groundmass

are broad and often rectangular and may give lamellar extinctions of oligoclase-andesine. The pyroxene in the groundmass of the porphyrites is often partly decomposed. It is as a rule prismatic. A little interstitial glass, altered in the porphyrites, is generally present.

FOURTH ORDER OF THE HORNBLENDE-HYPERSTHENE-ANDESITES

(Groundmass felsitic, displaying a granular mosaic structure)

These are light and dark grey rocks showing usually macroscopic pyroxene and hornblende. They vary considerably in appearance from the open-textured rock to that with a granitoid coarsely crystalline aspect. They generally carry brown hornblende phenocrysts, but frequently these are represented by pseudomorphs; and they all have a felsitic groundmass. They are only separated by the absence of porphyritic quartz from the dacites of Vanua Levu, which are treated in the next sub-class. They present all stages from the crypto-crystalline to the holo-crystalline condition, but all show a groundmass which may be scanty in the more coarsely crystalline rocks.

These rocks are characteristic of some of the hills of the Ndrandramea district and of the isolated peaks of Vatu Kaisia and Na Raro. They include a large proportion of the acid andesites of the island, and all belong to the prismatic sub-order with prismatic pyroxene in the groundmass, and to the section with plagioclase phenocrysts. Their specific gravity ranges usually from 2.55 in the more acid and less crystalline types to 2.74 in the most crystalline and basic kinds.

In the typical slides they display phenocrysts of plagioclase, pyroxene, and brown hornblende in a microfelsitic groundmass formed evidently of felspar and quartz together with much prismatic pyroxene. They may be conveniently divided into three species according to the size of the "grain" of the groundmass.

Of the first species, where the "grain" is less than .01 mm., the rocks of Mount Ndrandramea are typical. They have a crypto-crystalline groundmass where the felsitic structure is in process of development and where the pyroxene prisms or micro-liths are very minute. The plagioclase phenocrysts (1 mm. in size) give extinctions of acid and medium andesine (10° — 20°), and are tabular, zoned, and contain abundant pale inclusions. The hornblende phenocrysts, except in the case of the rocks at the foot of

the hill, are represented by pseudomorphs in various stages of dispersion, so that this character is likely to be overlooked. The pyroxene phenocrysts are in most cases of the pale yellow feebly pleochroic rhombic type, but they may present intergrowths of both the monoclinic and rhombic forms. These are light grey rocks with a specific gravity increasing as one descends from the summit, where it is about 2.5, to the base where it is 2.7, a change corresponding with increase of the ferro-magnesian minerals and with the more crystalline structure of the groundmass.

The second species, where the "grain" of the mosaic is between .01 and .02 mm., is represented by the Vatu Kaisia rock and by that exposed in the opposite side of the gorge. They are granitoid in appearance and have a specific gravity of 2.68 to 2.71. Large porphyritic crystals of pyroxene and hornblende, the last sometimes 7 mm. in length, occur in a dark grey base. In the slide these phenocrysts together with those of plagioclase are displayed in a somewhat scanty holo-crystalline groundmass, where the "grain" of the mosaic averages .012 mm. The plagioclase phenocrysts are zoned, and give in different crystals extinctions in some cases of oligoclase-andesine (10° — 12°) and in others of andesine-labradorite (25° — 30°). The hornblende phenocrysts in their pseudomorphism illustrate the various stages of the process of conversion into fine granular and prismatic pyroxene. The least altered crystals have dark resorption borders and are at times deeply corroded. The pyroxene phenocrysts are for the most part rhombic; but intergrowths with the monoclinic form occur. The pyroxene of the groundmass consists for the most part of small rhombic prisms averaging .05 mm. in length.

The third species, where the groundmass may be described as a coarse mosaic with a "grain" between .02 and .03 mm., is represented by the rocks of the peak of Na Raro and of Mount Thokasinga in the Ndrandramea district.

The Na Raro rocks are light grey with a specific gravity in the unweathered state of about 2.6, and display macroscopic crystals of glassy plagioclase and hornblende. In the slide they exhibit tabular phenocrysts of the plagioclase, together with dark pseudomorphs after hornblende, in a coarsely felsitic groundmass (grain .022 mm.) where a little very fine prismatic pyroxene, apparently rhombic, occurs. There is also a little altered interstitial glass. The plagioclase phenocrysts are zoned and give extinctions of 15° to 25° (acid and basic andesine), whilst they often show magma inclusions. An interesting feature of these rocks is concerned

with the rarity or absence of phenocrysts of pyroxene. They are to be seen, however, in the process of being built up within the substance of the hornblende pseudomorphs, which consist entirely of minute prisms and granules of pyroxene and of fine magnetite. The process seems to consist in the formation of parallel layers of rhombic and monoclinic pyroxene.

The Thoka-singa rocks are more basic (spec. grav. 2·72 to 2·74), and in the scanty holo-crystalline groundmass approach the plutonic type. They are dark grey granitoid rocks displaying abundant macroscopic pyroxene crystals 2 to 3 mm. long. The original hornblende phenocrysts are only represented by traces of pseudomorphs of fine pyroxene and magnetite, the process of dispersion, described on page 307, being almost completed. The pyroxene phenocrysts are mostly rhombic ; but intergrowths with the monoclinic form occur. The "grain" of the mosaic of the groundmass is coarse (·023 mm.), and there is a fair amount of prismatic with a little granular pyroxene, the prisms, ·04 mm. long, giving usually straight extinctions, whilst the granules are apparently monoclinic.

SUB-CLASS QUARTZ-HORNBLENDE-HYPERSTHENE-ANDESITES OR DACITES

These rocks are infrequent. They compose in mass the adjacent mountains of Ngaingai and Wawa Levu in the Ndrandramea district, and appear also on the lower slopes of the neighbouring mountain of Navuningumu. They differ chiefly from the hornblende-hypersthene-andesites in the presence of porphyritic quartz, which, however, is not as a rule abundant. In their general origin and affinities and in their mode of occurrence they cannot be separated from the two sub-classes of hypersthene-andesites and hornblende-hypersthene-andesites before described. They all belong to the felsitic order of the sub-class, and all are referred to the sub-order with prismatic pyroxene and to the section with plagioclase phenocrysts.

They are light grey rocks, with a specific gravity of 2·57 to 2·61, showing usually dark pseudomorphs after hornblende and a little porphyritic quartz. In the slide they display these pseudomorphs and quartz crystals, associated with abundant plagioclase phenocrysts, in a felsitic groundmass, evidently a mixture of felspar and quartz, with fine pyroxene, mostly prismatic and rhombic. Pyroxene phenocrysts are absent or rare ; but they may be seen in process of formation in the substance of the hornblende-pseudo-

morphs. It is only at times, as in the instance of the Navuningumu rock, that the brown hornblende phenocrysts are in part unchanged and that complete pyroxene phenocrysts occur. In such cases the last may be entirely rhombic, or may exhibit at times intergrowths with the monoclinic form.

The plagioclase phenocrysts, 2 mm. in size, are often tabular and zoned and give two sets of extinctions, indicating acid and basic andesine. Their abundant inclusions are arranged in zones. The quartz-crystals, 1 to 2 mm. in size, present hexagonal sections with rounded angles. They are sometimes traversed by cracks occupied by iron oxide films. The pseudomorphs after hornblende, which consist of fine pyroxene mixed with magnetite, exhibit often the building up in their interior of pyroxene phenocrysts, apparently rhombic, by long parallel rows of stout prisms. In other cases the pseudomorphs display the different stages of dispersion. The fine pyroxene of the groundmass consists mostly of rhombic prisms (.02—.06 mm. long) with some granules. The "grain" of the groundmass is usually between .01 and .02 mm. There is little or no residual glass.

The rocks of Wawa Levu and Ngaingai are closely similar, but they differ in the size of the prismatic pyroxene of the groundmass, which is coarser in the first-named mountain (.055 mm. long) than it is in the second (.025 mm. long). In both the "grain" of the mosaic is about the same (.014 mm.).

TABULAR COMPARISON OF THE ACID ANDESITES OF VANUA LEVU.

NOTE.—The figures in the columns headed "Felsitic" and "Rhombic" refer to the size in millimetres of the felsitic "grain" and the larger pyroxene prisms.

Locality.	Sp. Gr.	Phenocrysts.						Groundmass.		
		Plagioclase.	Quartz.	Hornblende or its pseudomorph.	Rhombic Pyroxene.	Monoclinic Pyroxene.	Structure.		Pyroxene.	
							Felsitic.	Orthophyric.	Rhombic.	Monoclinic.
Ngaingai, summit . . .	2'57	+	+	+ pseudom.	...	...	+ '014	...	+ '03	...
Ngaingai, lower part . .	2'57	+	+	+ pseudom.	...	...	+ '013	...	+ '02	...
Wawa-levu, 1,500 feet . .	2'61	+	+	+ pseudom.	...	...	+ '015	...	+ '05	...
Wawa-levu, 1,500 feet . .	2'61	+	+	+ pseudom.	...	...	+ '014	...	+ '06	...
Wawa-levu, west side of base but not on mountain	2'57	+	+	+ pseudom. in great part	+	...	+ '022	...	+ '04	...
Ndrandramea, summit . .	2'44	+	...	only traces of pseudom.	+	+ scanty	+ '007 hemi- crystalline	...	+ '01	...
Ndrandramea, 1,600 feet .	2'58	+	...	+ only traces of pseudom.	+	+ scanty	+ '008 hemi- crystalline	...	+ '01	...
Ndrandramea, 1,200 feet .	2'68	+	...	? only traces of pseudom.	+	?	+ '008 hemi- crystalline	...	+ '01	...
Ndrandramea, saddle at base	2'71	+	...	+	+	?	+ '009 crystalline	...	+ '01	...

Kalakala, near base . . .	2'61	+	...	+	pseudom. in part	+	...	+	'02	...	+	'01	...
Navuningumu : near base {	2'65	+	...	+	+	+	+	+	'02	...	+	'03	?
	2'48	+	+	+	+	+	...	+	'018	...	+	?	...
Thokasinga	2'74	+	...	+	+	+	+	+	'024	...	+	'03	+
Thokasinga	2'72	+	...	+	...	...	+	+	'023	...	+	'04	+
Na Raro, upper part . .	2'58	+	...	+	+	+	...	...	'02	...	+	'01 scanty	...
Na Raro	2'58	+	...	...	+	+	...	...	'022	...	+	'01 scanty	...
Vatu Kaisia	2'71	+	...	+	+	+	...	...	'013	...	+	'05	...
Vatu Kaisia, opposite to .	2'68	+	...	+	+	+	...	...	'01	...	+	'05	...
Soloa-levu, upper part . .	2'54	+	...	+	...	...	+	+	...	+	+	'06	...
Soloa-levu, upper part . .	2'57	+	...	+	...	...	+	+	...	+	+	'05	...
Soloa-levu, near base . .	2'62	+	...	+	...	...	+	+	...	+	+	'06	+
Soloa-levu, near base . .	2'61	+	...	+	...	...	+	+	...	+	+	'06	+
													scanty
													+
													scanty

Note on the Rhombic Pyroxene of the three foregoing sub-classes of the Acid Andesites.—The term “hypersthene” has been here used as a convenient expression equivalent to “rhombic pyroxene.” The mineral is always a little pleochroic and is never colourless, and it is only in very rare cases that the term “enstatite” could be used. As a matter of fact there is practically only one form of rhombic pyroxene represented in my collections whether in acid or basic andesites or in hemi-crystalline and plutonic rocks. In the acid andesites it occurs not only as phenocrysts but also as minute prisms forming a constituent of the groundmass.

This mineral, when composing the phenocrysts, presents itself usually as single untwinned prisms which exhibit the typical octagonal cross-sections with much reduced prism-faces. The prismatic sections give straight extinctions; whilst with the cross-sections we obtain straight extinctions parallel with the pinakoid faces. The colour in transmitted light is pale brownish yellow. The pleochroism, though usually feeble, is quite distinct, the colour being pale yellow when the prism lies parallel with the long axis of the lower nicol, and almost white when it lies across. Not infrequently these phenocrysts behave abnormally and give small oblique extinctions. This is often the case when monoclinic pyroxene occurs in the same section. The association of the two pyroxenes in one crystal can in some cases be clearly recognised. At one time a plate of pyroxene exhibits itself as a coarse aggregate of the two pyroxenes. At other times the two occur as parallel intergrowths, as in the accompanying figure. But it is rarely that such intergrowths are so typically displayed, the reason of which has been supplied by Zirkel in his *Lehrbuch der Petrographie*; 2nd edit.: I. 271.

Note on the “magmatic paramorphism”¹ of the hornblende phenocrysts.—Reference has before been made in the general description of these rocks to the dark alteration margins of the hornblende phenocrysts. The dark borders display the “bacillary” structure noticed by Renard in the case of some hornblende andesites from Kandavu in the same group of islands,² being composed of minute granules and parallel prisms of pyroxene and also of magnetite grains. With the Kandavu rocks Renard observed that the tiny pyroxenes were colourless or

¹ I have borrowed this term from Rosenbusch's *Microscopical Physiography of the Rock-making Minerals*, translated by Iddings.

² *Challenger Reports*, Physics and Chemistry II.

greenish and had an extinction angle of 40° . In the Vanua Levu rocks, however, there is a mixture in these dark margins of both monoclinic and rhombic pyroxene; and the process may be observed in all stages as it advances into the interior of the crystal, until a dark pseudomorph or paramorph of pyroxene and magnetite results. When the magnetite prevails, the pseudomorph may ultimately form a black patch in which the process is obscured. But when, as is generally the case, the pyroxenes are more frequent, it occurs as a dark grey mass.

Finally follows the dispersion of the pseudomorph, which first becomes a loosely arranged aggregate of the two pyroxenes and magnetite, and then breaks down, and at length is only represented by small pale patches of its original constituents. These patches are easily recognisable, and in not a few rock-sections offer the only indication of the previously existing hornblende phenocryst. There can be little doubt that this is the source of much at least of the often abundant pyroxenes of the groundmass, which are usually most frequent in the vicinity of the patches.

In the earliest stage when the dark border alone exists, it is not easy to distinguish the one pyroxene from the other, the granules and prisms being colourless and very minute, less than $\cdot 01$ in size. But in a far advanced stage of the paramorphism the granules and prisms become sometimes much larger, the first attaining a breadth of $\cdot 04$ and $\cdot 05$ mm. and the last a length of $\cdot 15$ mm. Finally the interior of the paramorph is seen to be more or less completely composed of very pale brown augite and pale yellow rhombic pyroxene in coarse grains and prisms, the first distinguished by its oblique extinction of 30° to 35° , the last recognised by its straight extinction and feeble though distinct pleochroism.

Although as a rule the paramorph becomes dispersed and its pyroxene constituents are added to the groundmass, it sometimes exhibits a change of another character. In this case the outer portion is alone dispersed, whilst the growth of a single large crystal of pyroxene proceeds within the mass. In a later stage, when the dispersion of the outer part is complete, we have a fresh-looking pyroxene phenocryst with unformed edges, on the borders of which little granules and prisms of pyroxene may be seen arranging themselves, as if the crystal-building was still in progress, or rather as if it had been interrupted and left unfinished by the too rapid dispersion of the outer portions of the paramorph.

It will be gathered from the above that the source of the pyroxene of the groundmass is to be found in the magmatic paramorphism of the porphyritic hornblende. The hornblende is dark-brown, markedly pleochroic, and extinctions up to 15° are given in prismatic sections. It is well known that the conversion of a hornblende crystal into an aggregate of pyroxene prisms and magnetite was long since experimentally effected by Doelter and Hussak by immersing the hornblende in molten basalt, andesite, &c.¹ I would imagine that the transformation of the hornblende and the dispersion of the paramorph occurred under two conditions; in the first case whilst the "flow" was still in motion when the resulting pyroxene would be mixed up in the magma; in the second case after movement had ceased, but before consolidation of the groundmass, when a paramorph or pseudomorph would be formed.

OLIGOCLASE-TRACHYTES

The term "trachyte" is here applied in a general sense to a group of light-grey intrusive acid rocks, having a specific gravity when compact of 2.4 to 2.45 and showing phenocrysts of glassy felspar, but not of quartz. These rocks, which are especially characteristic of the districts around Tawaki and Mount Thuku and of the Wainikoro sea-border, are often open-textured and sometimes a little vesicular, whilst several of them exhibit some degree of alteration in the groundmass. In all cases they appear to be intrusions rather than surface-flows; and at times they display a columnar structure.²

The difference between the oligoclase-trachytes in various localities appears to be mainly concerned with the varying degrees of crystallisation. There are two principal varieties. In the most crystalline type there are small phenocrysts of glassy felspar and a few of pale augite, the angle of extinction of the last being over 30 degrees. The felspar phenocrysts, which contain but few inclusions and have sharp rectilinear outlines, in most cases show zoning and give lamellar extinction of 5° to 12° indicating oligoclase; but some of them have the tabular untwinned or simple twinned form of sanidine. The groundmass is in the main composed of minute felspar-lathes, less than .1 mm. in length, arranged in a dense plexus, and giving nearly straight extinctions.

¹ *Neues Jahrb. für Mineralogie*, 1884.

² For their mode of occurrence, see pp. 215, 220, 230-233.

But it also contains a number of scattered larger felspar-lathes averaging .2 mm. in length and giving extinctions of 5° when simple, and of 8° to 10° when lamellar. There is also some small prismatic augite in the groundmass but often decomposing. The original interstitial glass is represented by numerous reddish-brown patches of devitrified glass.

In the second type of these trachytes, the rock is more open in texture and is at times vesicular, the specific gravity being usually less than 2.4. The general characters are much the same, but sanidine is better represented among the phenocrysts, and the groundmass is more blurred; but when the felspar-lathes are distinct they give an extinction either nearly straight or from 4° to 8° , according as they are simple or display lamellæ. The augite of the groundmass is scanty and more or less decomposed; whilst the interstitial glass when unaltered is in fair quantity and nearly isotropic.

The alteration observed in several of these oligoclase-trachytes is restricted chiefly to the interstitial glass in which secondary quartz and at times calcite and viridite are developed. Scarcely any of them are quite free from these changes.¹

The pitchstone or vitreous form of these trachytes is displayed in the blocks of an agglomerate-tuff between Tawaki and Mount Thuku. It has a specific gravity of 2.36, is dark-brown, and has a conchoidal fracture. Phenocrysts of felspar, mostly oligoclase, with extinction-angles of 5° to 11° , and often penetrated by the magma, are inclosed in a semi-isotropic groundmass showing incipient development of felspar and other darker microliths. There are also a few small phenocrysts of pale augite.

QUARTZ PORPHYRIES AND RHYOLITIC ROCKS

Wichmann when he wrote in 1882 that no quartz-bearing younger eruptive rocks had hitherto been observed either in Fiji or in the South Sea Islands generally, had apparently overlooked Dana's observations in the Fijian group. The American geologist² refers to a rock found on the north-east shores of Vanua Levu which exhibited in a greenish base thickly disseminated crystals of quartz (bipyramidal dodecahedrons, $\frac{1}{8}$ of an inch in diameter) and glassy felspar, together with a few sphene crystals.

¹ Highly altered rocks of this class are exposed at the base of Mount Nailohta as described on p. 215.

² See work quoted on p. 218.

Quartz porphyries, akin to the rhyolites, are especially characteristic of the north-east part of the island, to which in fact they are entirely confined. They perhaps are best represented in the vicinity of Mount Thuku and in the neighbourhood of the mouth of the Wainikoro River. None of my specimens have the fresh appearance of the Lipari rhyolites and all are more or less altered. Their specific gravity does not exceed 2.4, and they are for the most part intrusive in character.

A rock frequently exposed between Tawaki and Mount Thuku¹ contains abundant phenocrysts of glassy felspar (oligoclase and sanidine) and quartz in a greenish opaque groundmass having a blurred microfelsitic structure. There appears to have been a secondary devitrification of the groundmass since consolidation. The porphyritic quartz crystals are rounded and about 2 mm. in diameter.

Another rock displayed in the coast-cliffs on the north side of Natewa Bay, a mile east of Mount Thuku, has a somewhat banded appearance. It shows crystals of quartz, more or less rounded and 3 to 4 mm. in diameter, together with phenocrysts of glassy felspar (oligoclase with lamellar extinction of 5° and sanidine). The groundmass displays traces of spherulites and is in places semi-isotropic; but for the most part it is microfelsitic.

The type of rock found in the Wainikoro district and in the adjacent sea-border, where it may be observed forming dykes in the pumice-tuffs, is light-grey and loose-textured with a specific gravity of 2.1. It exhibits small phenocrysts of quartz and of glassy felspar (oligoclase 5° to 12°, and sanidine), with, in one locality only, a scanty amount of dark green hornblende yielding extinctions up to 20°. The quartz crystals, which are 1 to 2 mm. in size, are sometimes bipyramidal; but are often rounded and have fused-like outer surfaces. The groundmass is semi-isotropic with a blurred aspect, and shows traces of spherulites and numerous crystallites, with occasional felspar-lathes giving a nearly straight extinction.

An extensively altered quartz porphyry of a different type is associated with other altered rocks at the base of Mount Nailoia. It has a specific gravity of 2.54, and displays large opaque crystals of plagioclase, 2 to 5 mm. in size with small quartz crystals 1 to 2 mm. across, in a grey compact matrix. The first-named shows the felspar to be mostly replaced by alteration products; but occasionally a lamellar extinction of 6° or 7° can be observed.

¹ See p. 230.

The quartz crystals are rounded and penetrated by the magma, and contain numerous strings of fluid-cavities. The groundmass was originally spherulitic; but this structure is more or less disguised by the development of a mosaic of chalcedonic quartz. It shows some micro-porphyrific patches of viridite and calcite. A singular altered white rhyolitic rock is exposed on the north coast of Natewa Bay between Natasa and Sangani, where it is associated with altered tuffs. It is compact with a conchoidal fracture and has a specific gravity of 2.48. The hand-specimen has a banded appearance. Under the microscope it appears as a rhyolitic glass for the most part devitrified and rendered opaque by the formation of secondary silica. Much of it presents a micro-felsitic structure, the bands appearing as semi-opaque streaks.

Glassy forms of the quartz porphyries or intrusive rhyolitic rocks are extensively represented in the pumice-tuffs of the Undu Promontory and of the coasts between the Langa-linga river and Lambasa. These tuffs will be found described on page 336. Fragments of a grey rhyolitic glass looking like perlite are inclosed in the pumice-tuffs near the mouth of the Wainikoro River. Under the microscope it is displayed as a colourless glass inclosing phenocrysts of sanidine, oligoclase (ext. 4°), and quartz, the last with rounded outlines and a fused-like outer surface. The glass shows in places perlitic cracks; but it is mainly characterised by a vacuolar structure, the minute cavities being lengthened out in the direction of the flow and displaying eddy-currents around the phenocrysts. The elongated steam-cavities sometimes contain water, but are usually more or less filled with granular materials.

CHAPTER XXII

BASIC GLASSES AND VOLCANIC AGGLOMERATES

BASIC PITCHSTONE AND BASIC GLASS

IT is not possible to draw a sharp distinction between the pitchstone and the purely vitreous condition of these glasses. The following remarks will therefore apply to both.

Regarded as components of the pitchstone-tuffs and palagonite-tuffs these rocks have a very extensive distribution in the island; but in the massive state they are hardly ever to be found, whilst in the form of agglomerates they are only frequent in certain localities, as in the cliffs of the Korotini Bluff, in the vicinity of Mbale-mbale, on the slopes of Soloa Levu, and in the dividing ridge between the Mbua and Lekutu plains. On rare occasions they are to be found in a rubbly condition, as in the upper part of a basaltic flow described on p. 92, or they may form veins in a more crystalline basaltic rock as at Vatulele Bay. Their specific gravity ranges from 2·61 to 2·77, and they fuse readily before the blow-pipe, the melting beginning in the ordinary flame. Since they are not dissolved under any condition in HCl, they would be referred to the old hyalomelane group of basic glasses.

One of the most interesting of these rocks occurs on the slopes of Soloa Levu. As displayed on the south-west slope, it presents itself as a brownish-black rock with a specific gravity of 2·61 and exhibiting large porphyritic crystals (6 to 8 mm.) of plagioclase. It is generally compact, but it is in places a little vesicular, the minute cavities being often filled with a zeolite. The mode of occurrence of this pitchstone-porphyry is described on p. 104. In the slide the plagioclase phenocrysts give lamellar extinctions (21° — 27°) of andesine labradorite, and have regular outlines, with but few inclusions of the glassy magma. There are also a few

small phenocrysts of augite with dark rounded borders and showing in some cases lamellar twinning. The groundmass is a brown rather turbid glass in which dark points of devitrification occur. It is traversed by cracks that also penetrate the felspar phenocrysts. These cracks are filled with a feebly refractive material like palagonite; and there are traces of the early stage of the palagonitic change in one or two places. This is of importance, because on the north-west side of the hill occurs the same rock, in which the basic glass has been converted into a reddish-brown almost opaque palagonite; but in this case the porphyritic crystals of plagioclase are more affected by the magma, being rounded and extensively penetrated schiller-fashion by this material; whilst the augite phenocrysts are somewhat similarly affected. The altered glass is also vacuolar, the cavities being filled with a zeolite. There is an indication of some degree of crushing in the fracture of some of the felspar phenocrysts *in situ*. There appears to be a connection, as shown on p. 342, between the crushing of a basic glass and the formation of palagonite. It is noteworthy that with this change the specific gravity drops from 2.61 in the comparatively fresh rock to 2.14 in the palagonitised hydrated condition.

As another example of these basic pitchstones I will take that forming an agglomerate near Mbale-mbale. It has a specific gravity of 2.77 and displays phenocrysts of plagioclase, olivine, and augite. The first-named, which give the lamellar extinction of acid labradorite, (22° — 28°), are fresh-looking and only affected to a small extent by the magma. Those of olivine and augite are in much the same condition. The glass of the groundmass is rather turbid and displays numerous dark patches of incipient crystallisation, which in some cases prove to be composed of brush-like crystallites around a clear H-shaped nucleus, and in other cases have a more prismatic form.

A vitreous rock having some of the characters of a variolite is found near Narengali (see page 150). It, however, has the low specific gravity of 2.43 and is not readily fusible with the blow-pipe. It displays an imperfect spheroidal structure on a small scale, being made up of nodules, the largest having the size of a filbert. In the slide it appears as a grey glass made up of sheaf-like aggregates of fibre-like crystallites, apparently of felspar, with minute skeleton prisms of pyroxene in parallel arrangement, and is traversed by perlitic cracks.

THE VOLCANIC AGGLOMERATES

In this place my remarks will be chiefly confined to a summary of some of the leading features of these formations. The agglomerates, which pass by all gradations through the tuff-agglomerates into the submarine tuffs, rank amongst the most prevalent and the most conspicuous of the rocks exposed at the surface in this island. Their lithological characters vary according to the type of the massive rocks of the district. Thus in the Ndrandramea district the blocks are composed of the prevailing acid andesites. In the Koro-mbasanga district they are formed of hypersthene-augite-andesites. In the Korotini and Va-lili ranges they are composed of olivine basalts and basaltic andesites. The agglomerates derived from basaltic rocks and basic andesites are by far the most frequent, and it is to them that the following general observations apply.

The basic agglomerates and tuff-agglomerates are found almost everywhere and at all elevations up to 2,500 feet above the sea and over. They compose the inland cliffs and the long lines of precipitous declivities that give character to the valleys and gorges of the mountainous interior. The blocks are often scoriaceous and semi-vitreous, but the characters of the rocks will be found described on page 316. They are generally sub-angular and vary in size from a few inches to one or two feet; and, though sometimes heaped together in confusion, they will generally be found in the case of any extensive exposure to be rudely sorted according to size, or to present a rude horizontal arrangement.

The matrix varies much in amount, being sometimes barely appreciable and at other times so abundant that the deposit may be termed a tuff-agglomerate. Typically it has the character of the palagonite-tuffs of mixed composition described on page 326, being made up of fragments of palagonitised vacuolar basic glass, portions of crystals of plagioclase and augite, with the debris of the basic semi-vitreous and hemi-crystalline rocks forming the blocks. When it is scanty it contains neither carbonate of lime nor organic remains; but in the tuff-agglomerates it may be calcareous and may inclose tests of foraminifera and molluscan shells.

From the circumstance that the basic agglomerates overlie submarine sedimentary tuffs and clays almost everywhere, their submarine origin could alone be safely postulated. There are one or two localities that throw especial light on the conditions under

which these accumulations occurred. They are dealt with at some length in the general description of each district and only a brief reference can be made to some of their indications here.

The testimony supplied by the interesting exposures on the slopes of Mount Thambyu (page 178) goes to show that after the deposition of the foraminiferous tuffs and clays the stage of the agglomerates was ushered in gradually. The tuffs increased in coarseness, and afterwards they were covered up with an agglomerate formed of blocks at first only one or two inches in size, but afterwards of larger dimensions. . . . Curious evidence is afforded by the agglomerates of Mount Vungalei (page 213), where two beds of palagonite-tuff, at elevations of 900 and 1,700 feet, mark two pauses in the accumulation of the agglomerates. In each case the pause was introduced by the gradual decrease of the agglomerates which gave place by gradation to the tuffs. In each case also the pause was followed by a sudden renewal of the deposition of agglomerates.

With reference to the maximum thickness of these deposits, it would appear that on the slopes of the Korotini Range this amounts to some hundreds of feet, if we also include the tuff-agglomerates. Their origin is to be attributed partly to eruptions and partly to marine erosion. The two agencies although often associated were in their turns predominant in their different phases, and it is not too much to suppose that the agglomerates without arrangement, with scanty matrix, and composed of scoriaceous blocks, belong more to an eruptive period, and that those with abundant tufaceous matrix and sorted blocks are mainly the product of marine erosion. In either case the deposition was submarine.

But the history of these agglomerates and of their associated foraminiferous tuffs and clays must of necessity be a complicated one, since they indicate a minimum emergence of 2,500 feet. Their accumulation first began when a number of vents, in linear arrangement, were striving to raise their heads above the surface of the sea. It was continued after the waves had ultimately worn the volcanic islets down to below the sea-level, and the shoals became covered over with submarine deposits. Again and again no doubt this struggle between the eruptive agencies and the waves was renewed, until at length the great emergence began, and probably from that date the agency of marine erosion was predominant.

When on the island of Stromboli I had presented for my observation at least two modes of agglomerate-building under the sea. There was the ordinary work of the marine erosion of the

lava-cliffs, of which the beach represents but a small part of the result ; and there were the dribbling eruptions of the crater, from which at intervals of only a few minutes masses of semi-molten lava bounded down the steep slopes into the sea.

Note on the general characters of the rocks of the basic agglomerates.—In appearance the basic rocks forming the blocks are often very similar. They are usually compact blackish with a semi-vitreous aspect and display some plagioclase phenocrysts. But to enumerate the types to which they belong would be to go over much of the ground traversed in the classification of the basic rocks, whether olivine basalts, basaltic andesites, ordinary augite-andesites, or hypersthene-augite-andesites. The ground-mass as a rule contains much smoky glass, but the hemi-crystalline portions of it vary considerably in character. Whilst fine granular augite prevails, semi-ophitic coarser augites are not uncommon, and prismatic pyroxene, sometimes of the rhombic form, is represented in the groundmass of the rocks composing the agglomerates of Mount Thambeyu and of the Sokena Cliffs. In some localities, as on the south-west slopes of the Korotini Range, rocks of the basic pitchstone kind are predominant.

CHAPTER XXIII

CALCAREOUS FORMATIONS, VOLCANIC MUDS, PALAGONITE-TUFFS

THE classification that is adopted in my work on the geology of the Solomon group with respect to the calcareous formations and volcanic muds of those islands is only in part applicable to the calcareous rocks and volcanic deposits of Vanua Levu. Deposits strictly comparable with those of the Solomon Islands here exist, and have in some places an extensive distribution; but many others cannot be referred to that classification. In addition to the calcareous oozes and volcanic muds, such as are now forming off these reef-bound coasts, the result partly of marine erosion and partly of sub-aerial denudation, there are many kinds of submarine deposits in Vanua Levu that have been largely formed from the materials ejected by volcanic vents. Basic glasses, for instance, often finely vesicular and usually converted into palagonite, enter largely into the composition of submarine deposits that frequently form the surface from the sea-borders to the summits of the mountain-ranges; and it is by the degradation of a land-surface formed of such materials that the volcanic muds comparable to those of the Solomon Islands are mainly produced. It is therefore apparent that we have to distinguish here between the deposits of sedimentary and eruptive origin, a distinction, however, which is not always easy to make, since they are in both cases submarine, and doubtless were often in process of forming together. The deposits most prevalent in the island are the submarine tuffs partly sedimentary and partly eruptive in their origin and the overlying volcanic agglomerates. The first are usually palagonitic and calcareous and often contain organic remains, being usually associated with volcanic muds and clays mainly the product of marine erosion.

In connection with the employment of the terms "upraised" and "elevated" in the case of the Vanua Levu deposits I will take this opportunity to remark that I do not thereby commit myself to the view that there has been an actual upheaval of this region. This is a matter, however, that will be found discussed in Chapter XXVII.

THE UPRAISED CORAL LIMESTONES

These reef-limestones are scantily represented in the island, though one can scarcely doubt that they were once far more extensive, having been largely stripped off by the denuding agencies. They are mostly found on the south coast between Naindi Bay and Fawn Harbour, and rarely extend to heights greater than 20 or 30 feet above the sea, usually composing the sea cliffs and not occurring as a rule inland. Massive corals are often to be seen imbedded in their position of growth, as described in Chapter II.; and as far as the absence of signs of disturbance is concerned, these ancient reefs might owe their present situation, either to the withdrawal of the sea or to the upheaval of the land. Such reef-limestones exist over much of the Pacific, and they belong to the usual type of these rocks.

SHELLY AND FORAMINIFERAL LIMESTONES

These rocks are composed partly of reef-debris, partly of volcanic detritus, and partly of the tests of foraminifera (usually bottom forms), fragments of lamellibranchiate and gasteropod shells, together with those of pteropods, and other organic remains. Occasionally separate valves of the genera "Cardium" and "Ostraea" are inclosed in the limestone. These rocks have been evidently formed in rather shallow water. In places they overlie palagonite-tuffs and clays, also foraminiferal. Similar limestones are doubtless forming at the present time off the coast.

They are usually hard in texture and greyish or pale yellow in colour. They contain between 25 and 45 per cent. of carbonate of lime; whilst the residue consists of fragments of minerals (10 to 15 per cent.), including plagioclase, monoclinic and rhombic pyroxene, and occasionally brown hornblende, with siliceous casts of foraminifera (4 to 20 per cent.), mostly formed of chalcedonic silica but sometimes black and glauconitic; the remainder (30 to 40 per cent.) being composed of rounded and sub-angular portions of palagonite and semi-vitreous basic rocks, of which the larger vary from $\frac{1}{2}$ to 1 millimetre in diameter. In some cases the carbonate of lime of the

inclosed organic remains has been mainly replaced by more or less crystalline silica. In others a recrystallisation of the calcitic material is in progress, as described on page 131; and the matrix presents in places a mosaic of calcite.

These rocks have therefore been subject to some degree of alteration, the causes probably lying within the mass. They are, however, far from frequent. They are best represented in the upper valley of the Sarawanga River in the vicinity of Tembe-ni-ndio, where they reach to a height of about 250 feet above the sea. The greatest elevation at which I found them was in the mountainous interior of the Waikawa Promontory, where they occur at a height of 1,100 feet above the sea.

As samples, the results of the examination of two rocks from the Tembe-ni-ndio district are here appended:—

A.		
	Carbonate of lime	46 per cent.
Residue {	Fragments of palagonite and of semi-vitreous basic rocks	30 " "
	Minerals	12 " "
	Secondary silica replacing the carbonate of lime in the organic remains	12 , "
		<hr/> 100

It displays to the naked eye fragments of shells including pteropods, and numerous tests of foraminifera 2 or 3 millimetres in diameter. In the section it displays in addition coral debris and a considerable quantity of rounded and sub-angular pieces of palagonite and semi-vitreous basic rocks, usually less than a millimetre across, with smaller fragments of minerals (pyroxene and plagioclase), and much calcitic material in the matrix.

B.		
	Carbonate of lime	25 per cent.
	Debris of palagonite and of basic volcanic rocks	45 " "
	Minerals	10 " "
	Siliceous casts of foraminifera	20 " "
		<hr/> 100

The organic remains mainly consist of tests of foraminifera, many of which occur in the residue as colourless siliceous casts. The fragments, whether of minerals or of volcanic rocks, are usually less than half a millimetre across. The foraminifera are mostly small and of the "Globigerina" type; but there is a cast of a tube of some boring-mollusc, and fragments of shells also occur.

PTEROPOD-OOZE ROCKS

These rocks are bluish-grey when not exposed ; but through the hydration accompanying exposure they become much lighter in colour. They are crowded with pteropod shells, and contain also small gasteropod and lamellibranchiate shells together with tests of foraminifera both microscopic and macroscopic. They yield between 30 and 40 per cent. of carbonate of lime, the residue being made up of disintegrated palagonitic debris and fine clayey material derived from the same source, together with a fair amount of mineral fragments (10 per cent.) which include plagioclase, pyroxene, and brown hornblende, and measure in the case of the larger fragments between .1 and .4 mm. in diameter. Such rocks are somewhat friable and correspond with the pteropod-ooze rocks of the Solomon Islands ; but they are not very frequent, being best represented on the flanks of the basaltic table-land between the Wainunu and Yanawai rivers, as in the vicinity of the Nandua tea-plantation where they extend up to 500 feet above the sea. In this particular locality (see page 345) they overlie horizontally-stratified tuffs and clays, composed of the debris of a basic glass usually vacuolar but now for the most part converted into palagonite, and showing a few small tests of foraminifera.

These deposits are always either surface or incrusting formations. The circumstance of their passing down into characteristic palagonite-formations is repeated in the case of the Tembe-ni-ndio limestones, as observed on page 131 ; and there is no doubt that much of their non-calcareous material is derived from the disintegration of palagonite.

Sample of pteropod-ooze rock from below the Nandua tea-plantation.

	Carbonate of lime	38	per cent.
Residue {	Palagonitic debris and clayey material . .	51	" "
	Minerals	8	" "
	Casts of foraminifera	3	" "
		<hr/> 100	

Fine clayey material makes up the greater part (72 per cent.) of the residue. It presents the microscopic characters of material derived from the degradation of palagonite. Amongst the mineral fragments, of which the larger are .2 to .3 mm. in size, occur brown hornblende, pyroxene, felspar, magnetite, &c. The casts of foraminifera are usually glauconitic, but a few are of crystalline silica. A

number of curious little pellets of palagonite, oblong or oval in form, occur in the residue. Their size is .3 to .6 mm., and they apparently represent the minute amygdulæ of palagonite that occupy the vacuoles in an altered basic glass.

FORAMINIFEROUS VOLCANIC MUD-ROCKS

These deposits, which represent the "volcanic muds" forming around the coasts of volcanic islands, are more or less consolidated clay-rocks. They contain in varying numbers the tests of foraminifera with occasionally pteropod-shells. The former are usually minute and of the "*Globigerina*" type; but in some rocks larger bottom-forms prevail. The original colour of these deposits is bluish-grey, but as generally displayed they are pale-brown and considerably affected by hydration and are known as "soapstones" in the group. The ultimate effect of exposure is the production of a whitish or yellowish soapy rock that has lost all the carbonate of lime and all the organic remains and breaks down easily in the fingers. Such a crumbling material, when examined with a high power, cannot be distinguished from the products of the final disintegration of palagonite as described on page 348.

These deposits are frequently displayed in the lower regions up to elevations of 300 feet above the sea, incrusting the basaltic plains of Lekutu, Sarawanga, Ndreketi, and Lambasa, that occupy such a large area of the north side of the island, and exhibiting there in the prevailing horizontality of their beds the same indication that is presented by the vertical position of the columns of the under-lying basalt, namely, the comparative absence of disturbance during the emergence. At the foot of the mountains these deposits are interstratified with and finally overlaid by coarse palagonite-tuffs, also containing marine remains; and these are in their turn covered over by the agglomerates that often enter so largely into the composition of the mountainous backbone of the island. Such beds form apparently the lowest of a series which begins with the foraminiferous clay and ends with the agglomerate. But in some places, as has been noticed in the cases of the pteropod-ooze rock of Nandua, and of the shelly and foraminiferous limestone of Tembe-ni-ndio, beds composed largely of characteristic palagonite lie beneath.

In the elevated interior of the island these volcanic mud-rocks are usually concealed by the tuffs and agglomerates. Occasionally, however, they are to be seen exposed by landslips high up the

flanks of the mountains, as on the slopes of Thambyeu 1,000 feet above the sea. An interesting exposure of them is displayed in the heart of the island in the face of the Mbenutha cliffs where the elevation is about 1,100 feet. Here they are overlaid by a thick bed of agglomerate; and tuff-beds largely made up of vacuolar basic glass debris and showing a few foraminifera are interstratified with them; but they exhibit signs of considerable disturbance (see page 109).

These deposits contain between 5 and 25 per cent. of carbonate of lime, and as a rule about 90 per cent. of the residue consists of fine clayey material derived from the final degradation of palagonite and of basic rocks. The mineral fragments (plagioclase, augite, rhombic pyroxene, and occasionally hornblende) vary much in amount, their average proportion being 13 or 14 per cent. of the mass. Their size is usually less than .2 mm. and does not exceed .4 mm. Casts of foraminifera are nearly always present in the residue and form generally 3 or 4 per cent. of the whole deposit. Sometimes they are black and glauconitic; but more frequently they are white and composed of chalcedonic silica. Such casts represent on a small scale the results of the same silicifying operation to which the flints and silicified corals that occur so frequently on the surface in some localities owe their origin (see Chapter XXV.).

With regard to the age of these volcanic mud-rocks of Vanua Levu, it is most likely that as in the case of similar deposits in Viti Levu, which were examined by Mr. H. B. Brady, they are of post-tertiary origin. Samples of the Suva "soapstone" containing 5 or 6 per cent. of lime and displaying shells of foraminifera, pteropods, and other molluscs, were obtained from different heights up to 100 feet above the sea. Since 87 out of the 92 species of foraminifera represented in the deposits are known to be living now in the Pacific, Mr. Brady had no hesitation in assigning the beds to the post-tertiary epoch.¹

SAMPLES OF THE VOLCANIC MUD-ROCKS

A. *From districts west of Ndranimako, 100 feet above the sea.*

	Carbonate of lime	20 per cent.	
Residue	{ Fine debris of palagonite and semi-vitreous		
	{ basic rocks	62	" "
	{ Minerals	14	" "
	{ Casts of foraminifera	4	" "
		<hr/>	
		100	

¹ *Quart. Journ. Geolog. Soc.* xliv. 1888.

The organic remains consist mainly of tests of minute foraminifera of the "Globigerina" type, casts of which, both glauconitic and chalcedonic, occur in the residue. About 88 per cent. of the residue consist of fine clayey materials less than .25 mm. in size. The mineral fragments, which average about .1 mm. in diameter, are mostly of felspar with a little pyroxene and brown hornblende.

B. From the Mbenutha Cliffs, 1,100 feet above the sea.

Residue	Carbonate of lime	15 per cent.
	Fine material mainly derived from the degradation of palagonite	60 " "
	Minerals	23 " "
	Casts of foraminifera	2 " "
		<hr/> 100

This rock is somewhat hard, so that the proportion of fine clayey material, which is however large, cannot be accurately determined. It shows in places dark streaks composed of an abundance of minute and often perfect tabular crystals of zoned plagioclase and prisms of rhombic pyroxene, the size in neither case exceeding half a millimetre, both of them being derived from the acid andesites of the neighbourhood. In the slide it displays minute tests of foraminifera of the "Globigerina" type in a matrix formed mainly of palagonitic debris, fragments of minerals and semi-vitreous basic rocks. The larger fragments of the minerals and of the volcanic rocks do not exceed .15 mm.; but most of the material is very fine. The tests of the foraminifera are sometimes filled with the matrix, but often they are entirely of calcite and exhibit in polarised light a dark cross.

C. From between Natua and Mbatiri, about 290 feet above the sea.

Residue	Carbonate of lime	25 per cent.
	Fine material derived from the degradation of palagonite and of semi-vitreous basic rocks	62 " "
	Minerals	2 " "
	Casts of foraminifera	11 " "
		<hr/> 100

This is a relatively deep-water deposit, the foraminifera being minute and of the "Globigerina" type. About 90 per cent. of the residue consists of fine clayey material, with which the calcite is so intimately mixed that each particle is highly refractive and effervesces freely in an acid. The mineral fragments (pyroxene

and felspar) are very scanty, the largest being less than .25 mm. The white casts of foraminifera, composed of chalcedonic silica, form a conspicuous elements in the residue.

D. From the vicinity of Mhatiri, 100 feet above the sea.

Carbonate of lime	4 per cent.
Fine material derived from the degradation of palagonite	90 " "
Minerals	2 " "
Casts of foraminifera	4 " "
	<hr/> 100

About 94 per cent. of the residue consists of fine clayey material. The fragments of minerals are very scanty and are all less than .2 mm. in size. The casts of foraminifera are white and of chalcedonic silica. From the fineness of the materials and the small size and pelagic character of the foraminifera, this deposit may be regarded as formed in relatively deep water.

E. From the eastern flank of the Wainunu table-land, 200 feet above the sea.—This is a shallow-water deposit and contains, besides small gasteropod shells, large flat tests of foraminifera 5 or 6 mm. in diameter. It possesses 24 per cent. of carbonate of lime, 62 per cent. of palagonitic debris, &c., and 14 per cent. of minerals.

ALTERED VOLCANIC MUD-ROCKS

This group includes compact hard foraminiferous usually dark-brown rocks, which exhibit evidence of alteration in their induration, in the presence of pyrites, and in the chalcedonic quartz filling fine cracks in the rock-mass. Occasionally special types of alteration occur, one of which will be referred to in the description of some of the rocks given below. The proportion of carbonate of lime is generally small; but sometimes it amounts to 10 per cent. or more.

They admit of being examined in thin sections; and their true nature is at times so much disguised that I have taken them at first for aphanitic basic andesites. In the slide they display a few scattered tests of foraminifera of pelagic habit in a matrix composed of the fine debris of palagonite and of basic rocks, together with fragments of plagioclase and pyroxene. Most of the material is very fine, and the size of the largest mineral fragments does not exceed .2 mm.

Such rocks, however, are not very frequent. They may be

displayed on the flanks of mountain-ranges buried beneath basic tuffs and agglomerates, as in the case of Mount Mariko (page 187) and of the mountain-slope behind Mbale-mbale (page 158); or they may be found at much lower levels as at Savarekareka Bay (page 190), where, however, they assume sometimes a peculiar character. Though in the last-named locality the alteration is possibly connected with thermal metamorphism, it is probable that in most instances it is a normal interstitial change occurring in beds of some antiquity which are covered over by a considerable thickness of later deposits. In places, where these rocks have been subjected to much hydration in the weathering process, they become red in colour, as is found on the flanks of Mount Mariko.

SAMPLES OF THE ALTERED VOLCANIC MUD-ROCKS

A. From between 400 and 500 feet above the sea on the south slope of the Mariko Range. . . . The characters and mode of occurrence of this rock are described on page 187.

B. From an elevation of 1,100 feet on the south slope of the Korotini Range. . . . The description of the locality will be found on page 160.

This rock is hard and compact and looks like an altered basic rock showing a few minute specks of pyrites. It is composed of fine palagonitic debris, and small fragments of semi-vitreous basic rocks and of crystals of pyroxene and feldspar, none of the fragments exceeding .2 mm. in diameter. Tests of minute foraminifera, filled with matrix and of the "Globigerina" type, occur very scantily. There is little or no carbonate of lime; but secondary silica, both colloid and crystalline, is present as an alteration product.

C. From the vicinity of Yaroi, 30 feet above the sea. . . . The locality is described on page 189.

This is a dark grey hard compact rock, containing probably between 10 and 15 per cent. of carbonate of lime, and looking like unaltered limestone. In the section it displays minute tests of foraminifera of the "Globigerina" type in a matrix composed of fine disintegrated palagonitic material, impregnated with calcite and containing also fragments of minerals (augite and feldspar), none of which exceed .2 mm. in diameter. There are also a few similar-sized fragments of semi-vitreous basic rocks. Some fine

cracks in the rock-mass are filled with a quartz mosaic. The tests of the foraminifera remain calcitic; but their cavities are filled either with the matrix or with calcite or with a colourless fibro-radiate mineral polarising in blackish-blue hues.

D. From the south shore of Savarekareka Bay. . . . The locality is described on page 190.

This is a bright green hard compact rock with flinty fracture and not effervescing with an acid. In the slide it shows a few casts of foraminifera of the "Globigerina" type in a matrix composed mainly of fine debris (.01-.04 mm.) of felspar and pyroxene with much greenish opaque amorphous alteration products. The abundance of pyroxene is remarkable. The material of the tests of the foraminifera is altogether replaced by a greenish yellow mineral, occurring in grains and radiating prisms, apparently epidote.

E. From an elevation of 950 feet on Mount Thambeyu. . . . The locality is described on page 177.

A hard dark grey rock containing 10 or 15 per cent. of carbonate of lime and showing fine specks of pyrites. In the slide are displayed numerous tests of foraminifera of varying size up to .5 mm.; scattered patches of pyrites; fragments of a semi-vitreous basic rock, not exceeding .15 mm. in diameter, and of plagioclase and pyroxene; in a matrix of the finest debris of the same materials impregnated with granules of calcite. The tests of the foraminifera are filled either with calcite, showing a black cross in polarised light, or with a zeolite, or with pyrites, or with the matrix.

SUBMARINE BASIC TUFFS OF MIXED COMPOSITION

These tuffs, which are composed not only of palagonitic materials but also of the fine detritus of usually semi-vitreous basic rocks, rank first in frequency amongst the volcanic sedimentary deposits of the island. In their character they pass on the one hand into the foraminiferous volcanic mud-rocks or clay rocks and on the other into the tuff-breccias and tuff-agglomerates. We have here a series beginning with the agglomerate and ending with the clay that represents in a general sense the successive stages of the degradation of the same materials.

These tuffs occur at all elevations from the sea-border, where they may form the shore-cliffs, to the upper slopes and summits of the mountain-ranges, where they are found at elevations between

2,000 and 2,500 feet above the sea. In the interior of the island they are generally to be observed underlying the basic agglomerates. Wherever an extensive exposure of the agglomerates exists in the mountainous districts, these tuffs are as a rule to be found at the base of the cliffs. The precipitous bluff of agglomerate, that so often gives a character to the mountainous interior, and the line of cliff of the same formation that runs along the slopes, represent the work of landslips, as is shown by the huge masses of agglomerate lying on the ground below. These "slips" are not uncommon, and are due to the undermining influence of the springs that percolate through the tuffs and clays underlying the agglomerates.

When the tuffs are well displayed they as a rule show stratification. The bedding may be indicated either by distinct parting-lines or by alternating bands of varying degrees of coarseness. That these deposits, when occurring in mass in the upland regions, are often horizontal or but slightly inclined, is evidenced by the Nganga-turuturu Cliffs, 1,200 feet above the sea, which are described in Chapter VIII., in the line of cliffs behind Sealevu (Chapter XI.), and high up the slopes of Mount Thambeyu (Chapter XII.) as high as 1,500 feet. This is also shown in the circumstance that the line of junction with the overlying agglomerate, except in rare cases, as in that of the Mbenutha Cliffs, is generally horizontal. It is, however, not uncommon to find the beds exposed on the mountain-flanks dipping away from the axis of the range at a small angle, as on the slopes behind Mbale-mbale and in the Sokena Cliffs. In the lower regions, where these deposits are associated with the volcanic mud-rocks on the basaltic plains, they are but slightly inclined. On the other hand, as in the Kumbulau district, the sea-cliffs for some miles may be composed of tuffs more or less steeply tilted.

These tuffs are generally more or less compacted and have a greyish colour; but as usually exposed in a weathered condition they are often pale brown or yellowish and are more friable. They may be uniform in structure, or they may display thin seams of a marl-like clay, or they may contain numerous lapilli of vesicular basic glass extensively palagonitised. Not uncommonly they contain larger fragments of basic rocks, and when these are at all frequent the terms "agglomerate-tuff" or "tuff-agglomerate" have been employed according to the preponderance of either material.

Many of these tuffs show no effervescence with an acid; and this is especially the case with specimens at all weathered. On the other hand there are just as many that contain a little carbonate of lime, not usually more than 3 or 4 per cent., but sometimes

amounting to 12 or 13 per cent. It often happens in the case of a series of tuffs, apparently non-calcareous, that an occasional thin band of a fine clay-like rock contains a good percentage of lime. It is pointed out below, however, that the absence of effervescence does not necessarily imply the absence of foraminiferous tests.

Tests of foraminifera, often macroscopic bottom forms, together with shells of small gasteropods, are displayed at times ; but they are as a rule in such cases not frequent. I found foraminiferous tuffs at considerable heights in some localities, as for instance between 2,000 and 2,500 feet on the slopes of Mount Thambyeu (page 178), at an elevation of 1,850 feet on the south slope of the Korotini Range above Vatu-kawa (page 158), and between 2,000 and 2,400 feet on the summit of the range between Waisali and Sealevu (page 154). In the last-named locality, where the tuffs are coarse and often of the nature of agglomerate-tuffs, they are highly fossiliferous ; but such a character is exceptional.

The submarine origin of the tuffs can often be demonstrated in the absence of evidence of organic remains, as by their interstratification with foraminiferous clay rocks, such as we find at an elevation of 1,000 to 1,100 feet on the top of the "divide" between the Ndreketi and Lambasa basins. A single seam of marl-like rock displaying only a solitary test of a foraminifer in the slide may throw light on the origin of the coarser tuffs with which it is associated. The use of the microscope is essential in the case of some of the harder tuffs, where there has been a little alteration. Here casts of foraminifera may be observed, although no carbonate of lime is indicated by an acid. In some localities where no organic remains are evident in the tuff, fine waterworn gravel is to be noticed.

These deposits are composed as a rule of sub-angular fragments of semi-vitreous basic or basaltic rocks and of palagonite, together with fragments of plagioclase and pyroxene, the interspaces being filled with fine debris of the same materials. The relative proportion, however, of the three principal constituents varies considerably, the palagonite, for instance, being sometimes scanty and sometimes abundant. The size of the larger fragments in a tuff of the most common kind is about a millimetre ; but deposits rather finer and rather coarser are also frequent. In the very coarse tuffs and in the breccia-tuffs, where the larger materials are mostly of palagonite, the larger fragments may be a centimetre in size and even more, the interspaces being filled with fine debris of the same character cemented together often by carbonate of lime.

The fragments of semi-vitreous basic rocks forming a regular constituent of these tuffs are usually dark and opaque and display a few plagioclase lathes. They correspond with the type of the semi-vitreous basalt or basaltic andesite, of which the blocks of the overlying agglomerates are as a rule composed and are doubtless derived from the same source. Fragments of unaltered basic glass are rarely to be observed in these tuffs. It is as a rule all converted into palagonite. This material presents itself in various stages of secondary alteration, from the compact greenish or yellowish waxy mass to a white friable pulverulent substance, which represents the last stage of degradation. These changes will be found described on page 348. It can, however, be stated here that they are mainly concerned with hydration. In the case of the lapilli of finely vesicular basic glass, that is, of basic pumice, which are inclosed in some of the tuffs, all stages of the secondary alteration of palagonite are often exhibited, and the last stage of the change is merely indicated by a white powdery patch containing a few minute siliceous amygdules. The puzzling little white patches so common in basic tuffs merely represent lapilli of basic pumice that have been palagonitised, and then bleached and disintegrated by hydration.

The minerals are more or less abundant and may constitute a third of the whole mass. They include plagioclase, augite, rhombic pyroxene, and magnetite, olivine being rare and scanty. Entire crystals of any size are infrequent. However, crystals of augite, 5 or 6 mm. in length, are found in the tuffs at Naivaka and of the coast cliffs near the Salt Lake Passage. . . . It may be observed that zeolitic minerals which are frequently developed in the tuffs consisting almost entirely of palagonite are not typical of the tuffs of mixed composition.

There is nothing suggestive of recent eruptions in any of these formations. They were formed ages since on the sea-floor at varying depths around volcanic vents. Sometimes a cone was able to rear itself above the level of the sea ; but in most cases it rapidly succumbed to breaker-action. Three agencies, concerned with sub-aerial eruptions, submarine eruptions, and marine denudation, have co-operated in the production of these deposits, but their parts in the process have varied greatly. The last is indicated when the tuff is formed of a variety of basic rocks with but little palagonite. The tuffs containing much palagonite representing an original vacuolar basic glass are regarded as mainly the products of submarine-eruptions. In those cases where lapilli of altered

basic pumice occur in the deposit, sub-aerial eruptions are directly indicated. When an extensive exposure of these tuffs occurs, as in the case of the Nganga-turuturu Cliffs and in that of the section displayed near the hill of Korolevu (page 48), all three agencies are often illustrated.

SAMPLES OF THE SUBMARINE BASIC TUFFS OF MIXED COMPOSITION

A. As examples of the non-fossiliferous tuffs where the palagonite constituents do not predominate, I will take those exposed in beds in the coast cliffs and in the low hills in the vicinity of Na Tokalau in the Kumbulau peninsula (page 90). They are grey in colour and have the texture of a sandstone, being more or less compacted and showing no effervescence with an acid. They are composed of fragments of basic rocks and of minerals, varying in size from $\cdot 5$ to 1 mm., in a scanty matrix made up of fine detritus of the same materials and of palagonitic debris. The fragments of volcanic rocks are rounded and sub-angular, and formed mainly of a basaltic rock, with a black opaque groundmass showing some small plagioclase crystals and in places more or less palagonitised. There are also portions of a hemi-crystalline basic rock showing small augite crystals. The minerals entire and in fragments, which make up quite a third of the mass, are mostly of plagioclase, but monoclinic and rhombic pyroxene are also well represented. It is evident that through the alteration of the palagonitic constituents, which were probably more frequent when the tuffs were deposited, the structure of the matrix is somewhat disguised.

B. A yellowish grey tuff composing the cliffs on the north coast of Naivaka affords a good example of a tuff where the palagonitic materials predominate. It is somewhat fine-textured and displays a tendency to lamination. The powdered material effervesces slightly with an acid. In the slide it is exhibited as composed mainly of palagonite and of fragments of minerals, the latter making up about one-third of the whole and ranging in size usually between $\cdot 2$ and $\cdot 5$ mm. A number of more or less parallel fine cracks, filled with calcite and traversing also the inclosed crystals of plagioclase, together with small fragments of basic rocks are displayed in the section. There are a few fragments of semi-vitreous basic rocks, as just indicated, but the palagonite is the principal constituent. It shows numerous minute amygdules occupying the original vacuoles of the basic glass; and in its

substance occur irregular patches formed of a colourless semi-isotropic mineral which is either zeolitic or a form of opal. Plagioclase and augite compose the mineral fragments, the former prevailing. Although these tuffs are derived from a vent that was probably the last in eruption in this island, they display considerable alteration which is mainly connected with the secondary changes affecting the palagonite since the deposition of these materials.

C. As an example of the banded tuffs composed of coarse and fine materials I will take a compact grey rock forming one of the horizontal beds in the natural section exposed near the hill of Korolevu (p. 49). It is also an example of those tuffs which whilst not effervescing with an acid display a few casts of foraminifera in the slide. The alternating bands which are about a centimetre in thickness pass gradually into each other. The bands of finer materials are made up of sub-angular fragments, .1 to .2 mm. in size, of the dark opaque groundmass of a semi-vitreous basic rock and of a grey hemi-crystalline groundmass of an augite-andesite, together with palagonite more or less decomposed, and fragments of plagioclase and augite, whilst the interspaces are filled with the finer debris. The layers of coarse materials have much the same composition, the fragments varying usually between .5 and 1 mm. in diameter, with occasional larger pieces of palagonite 2 to 5 mm. in size representing original lapilli of a vacuolar basic glass. The tests of the foraminifera, which occur scantily in the layers of fine material, are all minute. They are filled with palagonitic material.

D. The tuffs prevailing on the higher flanks of the mountainous backbone of the island are well represented by those exposed at an elevation of 1,200 feet above the sea on the south slope of the Korotini Range behind Mbale-mbale. It is a somewhat coarse-grained rather hard grey rock effervescing feebly with an acid. It is composed of sub-angular or partly rounded fragments, 1 to 4 mm. in size, of various basic rocks, and of rather smaller fragments of plagioclase and augite, the interstices being filled up with fine debris of the same materials, in which a few minute tests of foraminifera of the "Globigerina" type may be observed. The basic rocks of which the fragments are formed comprise the following: (a) a grey aphanitic augite-andesite, with but little interstitial glass, presenting a parallel arrangement of the minute felspar-lathes which have an average length of .05 mm.; (b) a grey augite-ande-

site of coarser texture but in other respects similar, the felspar-lathes being about .1 mm. in length, whilst there is a little microphyritic plagioclase; (c) a semi-vitreous basaltic rock showing small porphyritic crystals of plagioclase and augite in a ground-mass usually black and opaque, but sometimes smoky and displaying felspar microliths; (d) a vacuolar basic glass more or less palagonitised.

E. As a specimen of the calcareous tuffs those exposed on the south slope of the Korotini Range at an elevation of 1,850 feet may be given. They contain about 11 per cent. of carbonate of lime and inclose a few tests of foraminifera 1 to 2 mm. in diameter. The other constituents are fragments of semi-vitreous basic rocks and of palagonite, together with fragments of plagioclase and pyroxene crystals and of an amorphous siliceous mineral which behaves optically like chalcedonic silica. When the rock is gently rubbed down, minute fragments of this white mineral can be picked out. They have a wrinkled surface and an irregular form and are not affected by acids. In polarised light they display a rude mosaic or an imperfect radiate structure.

F. As specimens of the fossiliferous agglomerate-tuffs composed mainly of palagonite, those exposed on the high mountain slopes of the Korotini Range at heights of 2,000 feet may be here cited. They are described on p. 154.

Note.—The examples of mixed tuffs above given represent only some of the principal types of these deposits. Short descriptions of others will be found in the detailed account of the geology of the island.

ALTERED BASIC TUFFS OF MIXED COMPOSITION

These form a group of hard compact rocks, the fragmental character of which is not always apparent in hand-specimens, microscopical examination of thin sections being usually required for the determination of their true nature. They are commonly exposed on the southern flanks of the Korotini Range at the back of Vatu-kawa and Nukumbolo. They are composed of compacted fragments, varying in different localities from 1 to 5 or 6 mm. in size, of a variety of semi-vitreous basic rocks, the matrix being scanty but often containing zeolites and secondary silica, whilst occasionally secondary calcite is developed. They contain no

organic remains, and palagonite when present is usually scanty, whilst viridite and similar materials represent the decomposition of the pyroxene. . . . A hard breccia-tuff found on the flanks of Mariko and in one or two other localities contains vesicular fragments, where the steam-holes are filled with opal or chalcedony, and the cracks traversing the matrix are also filled with this mineral.

The alteration of these tuffs has evidently arisen from a variety of causes. In some cases the change appears to be purely interstitial. In other times it has arisen from contact-metamorphism, or from hydro-thermal agencies, as in the case of the altered tuffs near the hot springs at Nukumbolo (p. 161).

SUBMARINE BASIC PUMICE TUFFS

These deposits, which, however, are not of frequent occurrence, are interstratified with volcanic mud-rocks in certain localities, as at the Mbenutha Cliffs (p. 110), and in the vicinity of the hill of Korolevu (p. 47). They indicate periods of volcanic activity during the deposition of the foraminiferous muds, with which they are associated, when the fine materials ejected from sub-aerial vents fell into the seas around.

Such tuffs are more or less compact and usually fine in texture. When the glass fragments are but slightly altered, the tuff-rock is dark grey ; but when the palagonitic change is well advanced, it becomes pale and yellowish. They are made up chiefly of small fragments of a bottle-green basic glass, which are as a rule vacuolar and sometimes fibrillar ; but it never happens that the pumiceous character is as pronounced as in acid pumice ; and in some cases the vacuoles or steam-pores are to be observed only in the minority of the fragments displayed in a slide. The size of the glass fragments is as a rule small, in some tuffs averaging only .1 mm. and in others .5 mm. ; but occasionally they may be 1 or 2 mm. in diameter.

Fragments of minerals (plagioclase and pyroxene) corresponding in size to the glass fragments are as a rule well represented, forming a fourth or a third of the mass. A little fine detritus of a semi-vitreous basic rock also occurs. Tested in an acid several of the tuffs either do not effervesce or give an indication of a small percentage of carbonate of lime ; whilst others effervesce freely. They usually display a few minute tests of foraminifera of the "Globigerina" type, the cavities of which are filled with fine palagonitic debris.

The palagonitic alteration is to be noticed in all cases ; but it varies considerably in its extent. In the dark grey tuffs it affects the margins only of a few of the glass-fragments. In the paler tuffs it has extended more into their substance, although the alteration is never more than partial. The pale greyish material filling up the interspaces is composed of disintegrated palagonite. The steam-pores or vacuoles are sometimes empty ; and at other times, especially where the palagonitic change has begun, they are filled with a granular alteration product. The glass fuses readily ; but is not affected by acids. It is clear and isotropic, showing however a few scattered microliths. These tuffs correspond with the hyalomelan-tuff from the island of Munia in this group as described by Wichmann ; but in that instance no mention is made of inclosed tests of foraminifera.

"CRUSH-TUFFS" FORMED OF BASIC GLASS

This is a remarkable group of compacted tuff-like rocks which as hand-specimens would be generally regarded as pitchstone-tuffs. Their detrital origin is, however, often very doubtful. They are composed of fragments of basic glass, carrying plagioclase phenocrysts, with the interspaces occupied by palagonite and by the finer debris of the glass and felspar. The larger glass fragments, which vary in different rocks from 1 or 2 to 4 or 5 mm. in size, have been crushed *in situ*, the broken portions often remaining more or less in position. These fragments are invested by palagonite and have eroded borders, as shown in the figure on page 342. The glass is bottle-green, non-vacuolar, fuses readily, and only at times displays incipient crystallisation. The explanation of the origin of these rocks is attempted in Chapter XXIV. They contain neither carbonate of lime nor organic remains. The most typical example is present in a bed underlying a pitchstone-agglomerate near Narengali (see page 149). It is not uncommon to find evidence of crushing in the glassy matrix of a pitchstone-agglomerate or of rubbly pitchstone, as in the Va Lili Ridge (142), the Korotini Bluff (157), and Mount Soloa Levu (313) ; and here also palagonite has been produced around the crushed fragments.

COARSE ZEOLITIC PALAGONITE-TUFFS

These deposits represent coarse kinds of the submarine tuffs of basic glass, in which the palagonitic change is far advanced, and

where zeolites and at times secondary calcite have been produced in abundance as a result of the alteration. They present themselves in the mass as mottled grey rocks which when examined in thin sections are seen to be composed in great part of fragments of more or less palagonitised vacuolar basic glass, whilst zeolites are extensively developed in numerous irregular cavities and in the interspaces. Although displaying no organic remains, their submarine character is indicated as at Nandua by the circumstance of their occurring as horizontal beds overlaid by pteropod-ooze deposits, or as at Tembe-ni-ndio by their forming part of a series of horizontal beds with a shelly limestone and a foraminiferous palagonite clay overlying them.

The fragments of bottle green basic glass vary usually between 1 and 4 millimetres. They were originally vacuolar and at times fibrillar from the lengthening out of the minute steam-pores; but through the palagonitic change these characters have been often disguised, and it is only at times that the unaltered glass is observed. Plagioclase and sometimes augite and occasionally olivine formed phenocrysts in the original glass. The zeolites, which include chabazite and natrolite, may be so extensively developed that they make up a fourth or a fifth of the rock mass. One may observe them in cavities where the walls are lined by fibrous natrolite with the cube-like crystals of chabazite occupying the interior. The calcite is usually subordinate to the zeolites, but sometimes the tuff contains as much as 10 per cent of this mineral, which is evidently of secondary origin. . . . The history of these tuffs in the district of Nandua and Ulu-i-ndali is no doubt applicable to these deposits in other localities. They are the products of submarine eruptions which shattered into fragments the extensive palagonite crusts of flows of basaltic lava. In Chapter XXIV. have attempted to show how palagonite is formed on a large scale in the case of such submarine displays of volcanic activity.

CHOCOLATE-COLOURED FORAMINIFEROUS PALAGONITE-MARLS

We have here hard, somewhat calcareous, clay-rocks which consist in great part (nine-tenths) of fine palagonite debris with some fragments of minerals and a little fine detritus of semi-vitreous basic rocks. Some hand-specimens would be taken for pure palagonite; but the fragmental nature appears at once in the slide. This is especially the case with a rock exposed in a stream-course near Kewa on the shores of Savu-savu Bay (see page 95). The

materials composing them are exceedingly fine, the largest fragments not usually exceeding .2 mm. As a rule they contain a little carbonate of lime and sometimes as much as 10 per cent., whilst a few tests of minute foraminifera are to be noticed in the slide. These deposits are horizontally bedded, and underlie a pteropod-ooze rock at Nandua and a shelly impure limestone at Tembe-ni-ndio. They are not very frequent, and sometimes approach in characters the volcanic-mud rocks, which, however, are much more mixed in composition. I regard them in the main as sedimentary deposits derived from the disintegration of the palagonitised vitreous surface of a submarine basaltic flow. They pass downward at Nandua, as described on page 345, into a rock of pure palagonite; and they are only to be found in localities where basaltic plains or plateaux are covered over with submarine deposits.

ACID PUMICE TUFFS

The general characters of these deposits are described on pages 10, 218, 220, 222, 223, 231, 233, &c. Such tuffs are restricted to the north-east part of the island east of Lambasa and Tawaki, and are well displayed in the coast cliffs. They are pale yellow or whitish, and are usually non-calcareous. They are composed of the debris of a vacuolar and fibrillar isotropic glass, nearly colourless and in some localities altered. Small crystals of quartz and of glassy felspar with bits of obsidian (up to 3 mm.) and lapilli of rhyolitic glass are inclosed in them. In places inclosed pieces of coral and coral rock indicate submarine deposition.

CHAPTER XXIV

PALAGONITE

FROM the sea-border to the mountain-top in almost every part of the island, palagonite occurs in a fragmental condition. It is only where tuffs are not found, as in the mountainous mass of Seatura, or where these deposits are formed of acid rocks as in the north-east portion of the island, that palagonite has not been observed. Perhaps, it is not too much to say that the later if not all the stages in the history of Vanua Levu are bound up with the history of this material. In this place I will only deal with certain features in the problem connected with the origin of palagonite which seem to receive further elucidation from my observations in this island. The literature is already extensive, and those interested in the matter will find in Zirkel's *Petrographie* and in the *Challenger* Report on Deep-Sea Deposits by Murray and Renard a good introduction to the subject.

In Vanua Levu we are confronted with the same difficulty that has perplexed geologists in various parts of the world. If we expected to find in this island the source of the enormous quantities of the basic glass that are represented by the palagonite of the tuffs, we should look in vain. Basic or basaltic glass usually occurs in agglomerates in the form of tachylytic pitchstones, as described on page 312, and is also found at times in basic pumiceous tuffs, as described on page 333; but it is far from frequent. Palagonite-rock, that is to say, a basaltic glass converted in mass into this substance, never came under my notice.

In order to clear the ground for the discussion of my own observations, I will quote from the report on deep-sea deposits above named. Fragments of basic glass undergoing the palagonite change are found everywhere in these deposits and especially in the red-clay

areas The hydro-chemical modifications determining the decomposition of these fragments into palagonite, and at the same time the formation of zeolites, have likewise resulted in the complete transformation of these lapilli into ferruginous argillaceous matter (p. 309). The authors, however, of this report do not attribute the frequent occurrence of fragments of basic glass on the bottom of the ocean to the buoyant powers of basic pumice. Unfortunately, the problem does not permit of such a simple solution. Basic volcanic glass, writes Prof. Renard, though known only from a few geological formations and from a few eruptions of recent volcanoes at the surface of the continents, appears in abundance and in most typical form among the products of submarine eruptions, as if the deep oceans had been in some way specially favourable to the development of this lithological type (p. 299).

The palagonite-tuffs of this island are described in detail in Chapter XXIII., and a few general remarks are alone needed here. This altered glass enters into the composition, to a greater or less extent and in varying stages of disintegration, of nearly all the submarine basic tuffs and clays. In the volcanic muds, however, and in the tuffs of mixed character, which are the prevailing deposits, it is associated with other components. Here the question of the origin of palagonite within the deposit does not as a rule arise, since there is nothing to indicate that this material was not derived from rocks previously palagonitised, and the point of main interest is connected with the last stages in the degradation of this substance. There are not a few cases, however, where, unless we assume that the lapilli of vesicular basic glass were ejected in the palagonitic condition from a volcanic vent, we must apparently regard the alteration as having occurred in the tuff. But even this will prove to be by no means a necessary consequence if it can be shown, as I have attempted to do below, that the palagonitic condition exists potentially in a particular type of basic glass and that the effect of hydration is not so much to produce but to make evident a condition that was previously latent.

It will be therefore of interest to determine whether palagonite occurs in this island independently of the tuff-deposits, and under such circumstances that it may be regarded as having been produced within the rock-mass. An example is afforded in the case of a basaltic flow near Soni-soni Island, which is fully described on page 92. Whilst the lower part of this flow is composed of a hemicrystalline basalt with scanty olivine, the upper portion is made of a basaltic glass which has been broken up or crushed "in

situ," the spaces between the fragments being filled with palagonite. It would seem from the peculiar erosion of the glass fragments that after the crushing a liquid magma occupied the interspaces, and afterwards solidified and underwent the palagonitic change.

In this connection it is noteworthy that in the sections of the lower hemicrystalline portion of the flow there are shown in the



MAGMA-LAKELET, '25 mm. in size, magnified 290 diameters, from a basalt at Navingiri. The groundmass, which is a smoky devitrified glass containing abundant felspar-lathes, is coloured black. The magma-lakelet is pale yellow in the slide and displays concentric lines of congelation. It behaves like palagonite.

groundmass collections of a palagonitic material forming, as I have termed them, "magma lakelets" of microscopic dimensions (25 mm. in average size). These "lakelets" are irregular in form, and are not uncommon amongst a certain type of basaltic rocks. One of them is figured above; and it may be added that they are best examined when displayed in a groundmass containing much

smoky, partly devitrified, glass. They are usually more or less opaque and reddish-brown or yellowish in colour, whilst they have often a marked zoned structure, the concentric bands conforming to the irregular contours of the lakelet. In the least affected stage the zones show fibrous devitrification across their breadth, but as the palagonitic change progresses the material becomes opaque. In the secondary changes, such as those associated with the early alteration of the propylites, these "magma lakelets" are the first affected. They then present alternating layers of calcite and viridite and are often bordered by magnetite.

If these "lakelets" were to be described as collections of residual glass, the description would be insufficient, since they may occur in the midst of a smoky, partially devitrified, glass. During the last stage in the consolidation of the basaltic mass, the magma-residuum that still retains its fluidity collects here and there in the crevices of the groundmass, and forms little pools of usually microscopic dimensions into which the felspar-lathes often protrude from the sides. These little pools or lakelets represent that portion of the yet fluid magma that during the last stage of consolidation is imprisoned in the stiffening mass—like the whey in a cheese—whilst the greater part of it has been squeezed into the cracks of the cooling mass, as occurs in a dyke-like intrusion below described, or has been extruded on its surface, as in the case of the basaltic flow above referred to.

As a suggestive instance of the formation of palagonite "in situ," I will now refer to a basic tuff-agglomerate on the plateau of Na Savu (see p. 81) which is penetrated by veins, a few inches thick, apparently composed of a finely brecciated pitchstone-tuff. In the section the material forming the veins is seen to be composed of fragments of basic glass (carrying porphyritic plagioclase and augite) which have been crushed in position, the interspaces being filled up with the finer debris of the glass and of the minerals together with palagonitic material. The glass fragments, which have lost their sharp edges and angles, are often palagonitised at the borders, and we thus get a patch of isotropic brown glass with a yellowish margin formed of a feebly refractive turbid substance. Where this border is not so evident, it is noticed that the edge of the glass is peculiarly eroded. The indication appears to be that the fissures in this agglomerate were filled with a basic magma that after its solidification into a glass was subjected to a crushing process, and that during this process a partial remelting of the glass took place which resulted in the

molecular change characteristic of palagonite. Since the unaltered glass-fragments fuse in the ordinary flame, it would seem that the heat developed during the crushing might be sufficient to partially remelt the glass without affecting the rock penetrated by the veins . . . It is of importance to note that in the palagonite-tuffs of the Canary Islands the change is often most complete along fissures, which thus present the appearance of being occupied by veins of pitchstone.¹

In this connection allusion may be made to a dyke-like mass of a rubbly semi-vitreous basaltic rock exposed at Vatu-lele Bay, described on page 184. It is penetrated in all directions by veins, 1 to 3 inches thick, of a tachylytic glass which begins to fuse in the ordinary flame. The glass is traversed by cracks which sometimes contain palagonite. The basalt, penetrated by the veins, has a smoky groundmass displaying imperfect felspar-lathes in a feebly refractive glassy base and containing a few small "magma-lakelets" that cannot be distinguished from palagonite.²

Near the mouth of the Narengali valley (see page 149) I found what appears to be a palagonite-tuff overlain by agglomerates formed of tachylytic pitchstone and of semi-vitreous amygdaloidal basalts. The tuff consists of fragments of a brown basic glass, the larger 1 to 2 millimetres in size, carrying porphyritic plagioclase, and fractured in position, the interspaces being filled with palagonite. The glass fragments possess the eroded margins indicated in the accompanying figure. It may be remarked that this type of tuff differs from that of the prevailing palagonite-tuffs in being rarely vacuolar, in the absence of marine organic remains, and in its homogeneous composition. It is described on page 334 under the head of "crush-tuffs." Whether it is derived from the destruction of a mass of basic glass that had previously undergone crushing and partial palagonisation I cannot say; but its characters point in the direction of this conclusion.³

In the foregoing pages it has been attempted to show that palagonitisation has taken place in the veins of basaltic glass traversing in one case a basic tuff agglomerate and in another case an intrusive basaltic mass, and that it has also occurred in the upper vitreous portion of a basaltic flow and in the materials now composing a so-called "crush-tuff." In order to explain this group of facts I venture to propose this theory.

¹ Zirkel's *Petrographie*, iii., 694.

² This basalt is not fusible in the ordinary blow-pipe flame.

³ In this connection see the description of the Soloa-levu pitchstone on p.312.

In certain types of basaltic lava,¹ when cooling and consolidation take place under peculiar conditions, such as we would expect to find in submarine eruptions, there is a residuum of the magma with relatively low fusibility that remains fluid after general solidification of the mass is well advanced. As the rock continues to consolidate, portions of this magma residuum become imprisoned in the mass, like whey in a cheese, giving rise to the "magma lakelets" above described; whilst other portions, during the contraction and fissuring accompanying the cooling process, are squeezed out into the cracks thus formed, or are intruded on the surface of the consolidating mass, as in the case of a submarine lava-flow. This solidified magma-residuum differs from the ordinary



Showing fragments of glass with eroded borders and of plagioclase with more even edges in a matrix of palagonite traversed by cracks. The length of the largest fragment is half a millimetre. The glass has been evidently fractured in position and this is true of one of the felspar fragments. It is also apparent that whatever its cause the erosion of the margins of the glass has been produced since the fracture.

basic glass not only in its lower degree of fusibility but in its mineral composition and in its molecular condition. It probably in the first place does not differ much in appearance from the typical glass, but it is an unstable substance and is capable under certain hydro-chemical conditions of developing the characters of palagonite.

In those cases where the occurrence of palagonite is associated with evidence of crushing, the process appears to be in a sense reversed, since partial palagonitisation of an ordinary basic glass takes place as a result of the elevation of temperature due to the

¹ See the note at the end of this chapter.

crushing. The heat thus developed is sufficient to partly fuse the glass; but since it is not great, it only affects the most fusible constituents, and the remelted material corresponds therefore to the magma-residuum of the consolidating mass, which is referred to in the previous paragraph. It has the same unstable characters and the same tendency to assume the palagonitic condition.

This theory centres around the relatively low fusibility of the magma-residuum that gives rise to palagonite. This degree of fusibility has yet to be ascertained, since according to the views here advanced it may even be much lower than that of tachylyte. It is, however, noteworthy that the melting-point of tachylyte is far below that of the more crystalline basaltic rocks, since it can be readily determined, as I have done in the instance of a dyke-like mass penetrated by tachylyte-veins before referred to, that the veins are composed of a much more fusible material than the rock-mass. From a very crude experiment I would infer that the melting-point of ordinary tachylyte is not much above that of lead (335° C). The fusion-point of an ordinary hemicrystalline basalt, according to the well-known experiments on the lavas of Vesuvius and Etna, would probably be over 1,000 degrees C.

Two interesting experiments, the one artificial, the other natural, may be here cited in connection with this view. Bunsen¹ more than half a century ago, as a result of some experiments in which he produced palagonite, arrived at the conclusion that the tuffs formed of this material are submarine deposits derived from the breaking up of previously formed palagonite-masses. Having obtained this substance by placing powdered basalt in an excess of melted potash-hydrate (Kalihydrat) and then adding water to the silicate of potash thus formed, he concluded that palagonite results from the reaction between glowing augitic-lavas and rocks rich in lime and other alkalies. Although Zirkel quotes in this connection the example where this material has been produced in the Cape de Verde Islands by basic lava flowing over limestone, he rejects Bunsen's explanation as inapplicable to extensive palagonite districts, such as occur in Iceland, though allowing that it would account for the local production of this substance.

I venture to think, however, that in these two experiments the general principles involved in the production of palagonite are partly illustrated. We may accept the results of an experiment without acquiescing in its interpretation. As I take it, it is in the partial wet fusion of the powdered basalt that the secret of this

¹ Quoted in Zirkel's *Petrographie*, iii., 689.

successful production of palagonite lies. In both these experiments some of the conditions of a submarine flow have been reproduced.

Whilst Rosenbusch established the true character of palagonite as the product of a peculiar alteration of a basic glass, Renard pointed out the conditions under which it was most typically and in greatest abundance formed. But Bunsen was happy in his suggestion that palagonite-tuffs are submarine deposits derived from the breaking up of previously formed palagonite masses. The question thus resolves itself into one concerning the conditions of submarine eruptions and the behaviour during consolidation of a submarine basaltic flow. In the nature of things the field of investigation is mainly restricted to the examination of ancient submarine basaltic flows that have been raised above the sea.

A remarkable series of beds exposed in a stream-course below the Nandua tea-estate may be here described in connection with the question of the origin of palagonite formations. As observed on page 86, this locality lies on the flanks of a basaltic plateau, which are incrustated with recent submarine deposits. A pteropod-ooze, containing also the tests of large and small foraminifera and the shells of small bivalves, is displayed on the sides of the stream-course for the first 150 feet of the descent. Below this, as shown in the diagram, is a declivity with a drop of 60 or 70 feet where there is a waterfall. Horizontal beds of the pteropod-ooze rock are exposed in the upper-third of this declivity; but below, they pass into a chocolate-coloured marl-like deposit also horizontally bedded, and sometimes having a banded appearance from the alternation of layers of different degrees of fineness. This rock contains 5 or 6 per cent. of carbonate of lime and incloses a few scattered tests of minute foraminifera of the "*Globigerina*" and "*Nodosaria*" types. In the slide the rock appears to be of massive palagonite inclosing a few felspar-lathes .1 to .3 mm. in length, and exhibiting a zeolite and calcite in the crevices and cracks. But it was not until I had discovered the tests of the foraminifera and had observed some fragments of larger crystals of plagioclase and a little detritus of a semi-vitreous basaltic rock that its clastic character was disclosed. The palagonite change has here to a great extent disguised the character of the deposit.

This palagonite-marl formation is 20 or 30 feet in thickness. It passed downward into a reddish-brown rubbly unstratified rock which falls to pieces in one's hands, breaking up into little cube-like masses an inch or two across. These masses display in their interior a radiate prismatic structure; but after drying they

crumble into small fragments exhibiting the same minute prismatic structure, the miniature prisms being about a millimetre in diameter. Fine cracks, filled with calcite and a zeolite, traverse this rock in all directions, and no doubt this peculiar structure arises from shrinkage.

My idea that I was dealing with a clay-rock affected by the proximity of an igneous intrusion was dispelled when the powdered material presented itself as pure palagonite with scarcely any mineral fragments. Unlike the marl above, it does not effervesce with an acid; and appears as a mass of compacted minute fragments of basic glass converted into palagonite, which is seemingly non-vacuolar, and containing about 15 per cent. of water.

In connection with the diagram it should be remarked that I did not find the palagonite-rock actually passing down into the

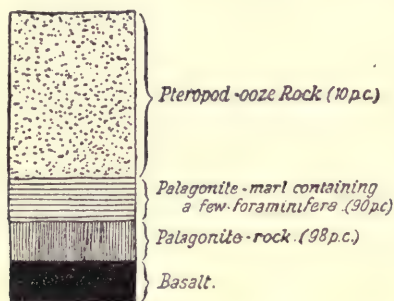


Diagram showing the succession of deposits below the Nandua tea-estat. The total thickness is about 250 feet. The figures refer to the proportion of palagonite.

basalt which, however, is exposed in the river-bed below. The whole district is characterised by columnar basalt, and the series of deposits here described have been formed on the flank of the great basaltic table-land of Wainunu. It is noteworthy that in the uppermost deposits of the pteropod-ooze palagonite forms a noticeable proportion (10—20 per cent.) of the residue; and perhaps most of the fine clayey material is thus derived. As noted on page 321, minute pellets of pure palagonite are not infrequent in the residue. Probably about 90 per cent. of the underlying marl consists of palagonite. In the lowest palagonite-rock the proportion would be quite 98 per cent.

Whilst it is apparent that we have represented in this series the covering of a submarine basaltic flow with submarine deposits,

it is also evident that the mode of junction between the flow and the overlying deposits is of an unexpected nature. Before drawing any inferences, it is necessary to point out that when we begin on *à priori* grounds to frame our notions as to the course of events on the surface of a submarine basaltic flow, we are entering a little known region of inquiry. I would, however, suggest in the light of the theory before advanced, the following explanation of the appearances presented by this series.

During the consolidation of the flow much of the magma-residuum that still retained its fluidity was extruded on the surface, where after solidification it became palagonitised. According to my view this would be the typical behaviour of submarine basaltic flows; but, owing to the unstable and perishable nature of the palagonitic crust of the flow, it would be rarely preserved in upheaved volcanic regions. There would probably be, as in the case of the Nandua series, no sharp line to be drawn between the palagonite-crust and the deposits subsequently covering it, deposits indeed that would derive no inconsiderable proportion of their materials from the disintegration of the crust itself. During and after the emergence of such a district of submarine eruptions the unstable palagonitic crust would be further subjected to the hydration resulting from weathering and similar agencies; and as a result of its final degradation there would often alone remain a bed of reddish argillaceous material.

In concluding these remarks on palagonite the following summary of the principal points here dwelt upon may be added:

(a) The basic glass, that undergoes the palagonitic change, is the vitreous form of the magma-residuum that in a particular type of basalt and under certain conditions remains fluid after the mass of the rock has solidified. During the last stage of the consolidation it is in part imprisoned in the "magma-lakelets" of the groundmass; whilst the rest of it is squeezed into cracks and fissures, or extruded on the surface of the flow.

(b) This glass differs from ordinary basic glass in its molecular condition, its mineral composition, its low degree of fusibility, and in its unstable character.

(c) The formation of palagonite in connection with the crushing of a basic glass is to be explained by the hypothesis that the heat developed during the crushing is sufficient to partially re-fuse the glass, the material thus produced corresponding to the magma-residuum of low degree of fusibility, which is above referred to.

(d) In submarine eruptions are to be found the conditions favouring the production of palagonite on a large scale. In the case of such basaltic flows it is probable that their upper portions are formed entirely of palagonite arising from the alteration of a vitreous magma-residuum extruded on the surface in the manner above described. Such a crust, as a result of shrinkage and other processes, would probably present itself to the geologist as a somewhat friable material, passing gradually into the overlying submarine deposits.

Note on the type of basalt found associated with palagonite.

The type is characterised, it would appear, rather by its structural features than by its mineral composition. It is the basalt of ophitic or semi-ophitic habit that would seem to be usually associated with palagonite; and since this habit is as a rule to be found where the groundmass displays large felspar-lathes in plexus arrangement, coarse augites, and at least a fair amount of smoky glass, it follows that a hemi-crystalline, ophitic or semi-ophitic, doleritic basalt is the type to be associated with palagonite.

This is the type of rock that forms the lower part of the basaltic flow near Kiombo, the upper part of which is largely palagonitic. To this structural type also belong most of the basalts in my collection where palagonite exists in the form of "magma-lakelets" in the groundmass. These "lakelets" are almost diagnostic of this type of basalt. Here also belongs the famous globular basalt of Acicastello on the coast of Sicily.¹ In such rocks the felspar-lathes form a mesh-work and vary usually in average length between .1 and .3 mm. The augites of the groundmass, typically semi-ophitic, range up to .1 mm. in size. They are always large, that is, over .03 mm., and this coarseness is another important indication.

¹ I have visited this locality on several occasions with the special object of studying the relation of the basalt to the associated palagonite-tuffs and clays. A general discussion of this question would be out of place here; but I may remark that the conclusion arrived at by me is that these deposits are not sedimentary but are entirely the result of the disintegration of palagonite *in situ*. This is quite opposed to the view of their sedimentary origin held by Dr. Johnston-Lavis, Prof. Platania, and other Italian geologists. . . . The basalt is scoriaceous, semi-vitreous, and semi-ophitic, and closely approaches the type of basalt above defined.

NOTE ON THE CHANGES PRODUCED THROUGH THE HYDRATION OF PALAGONITE.

Most of that which is detailed below is not according to my views palagonitisation, but the effect of hydration in the disintegration of this material. The initial molecular condition and the other characters which represent potentially the palagonitic change are not connected with hydration ; but are concerned with the causes before explained that led to the formation of a basic glass of such an unstable constitution. Indeed, there is good reason to believe that the changes to be now described may be observed under the ordinary influences of weathering in a wet region.

The early stages of alteration are well displayed in some of the tuffs formed mainly of basic vacuolar glass, the submarine character of which is often indicated by a few tests of foraminifera. Whilst the glass retains its original bottle-green colour, it loses the clean sharp conchoidal edges and displays rough and uneven or granular borders. With a high power the surface of the fragment is seen to be minutely pitted or pock-marked in places, the shallow circular pits, less than .01 mm. in diameter, being sometimes arranged in a row like a number of overlapping rain-prints. This process proceeds until all the surface is affected, and from this cause there is often an appearance of polygonal markings. The pock-marking, however, continues ; and as the pits encroach more and more on each other an irregularly wrinkled rough surface results. Up to this time the glass has retained much of its original colour ; but its clearness is replaced by turbidity, and collections of very minute rounded, rod-shaped, and irregular granules, composed of a colourless feebly polarising material, are displayed here and there in its substance, whilst some of the previously empty vacuoles are now filled with water.

In the next stage the hydration of the iron-oxides begins, and the glass becomes opaque and yellowish or reddish-brown, and has a more granular appearance, polarising feebly. Cracks now traverse the substance, and penetrate into the vacuoles, which, as they become filled with the alteration products, whether palagonitic, zeolitic, or siliceous, become ruptured and curiously distorted. The hydration and consequent disintegration continue until the deep stain of the iron-oxide is removed, and a semi-pulverulent whitish material remains. This is the history of the

little bleached powdery patches so common in basic tuffs, each representing originally a lapillus of basic pumice. This powder when examined with the microscope is shown to be made up of fine granular and tubercular materials which lose much of their distinctness when mounted in Canada balsam. It is not affected by boiling in HCl, and contains usually an abundance of minute siliceous oval amygdules that have been freed in the last stage of the disintegration of the palagonite.

Such is the story of the degradation of the palagonite daily in operation in the basic tuffs of this island. From this source is doubtless derived much of the finest constituents of the submarine clays so common over Vanua Levu.

Supplementary note on the occurrence of palagonite in the glassy matrix of pitchstone-agglomerates and in rubbly pitchstones.—In my last revision of the proofs I find that I have not laid sufficient stress on the production of palagonite under these conditions. The evidence of crushing is often very evident, and especial references to this point will be found in the index under "Pitchstone," and on page 334 under "Crush-tuffs."

CHAPTER XXV

SILICIFIED CORALS AND FLINTS

SILICIFIED corals, together with siliceous minerals (quartz, chalcedony, jasper, &c.) and siliceous concretions are evidently widely distributed in these islands. Kleinschmidt in his journal refers to large blocks of flint on the island of Ono, from which the natives used to obtain their musket-flints,¹ and he collected from this island as well as from Viti Levu, Ovalau, &c., numerous specimens of these and other siliceous minerals and rocks, such as hornstone, chalcedony and jasper, which were examined by Wichmann and described in his paper.² Mr. Andrews observed silicified corals on the summits and higher slopes of Vanua Mbalavu.³ The Fijian name for flints, "ngiwa" (thunderbolt) or "vatu-ngiwa" (stone-thunderbolt), affords a good instance of that curious superstition connected with the origin of these stones, which came also under my notice in the Solomon Islands,⁴ and in fact is widely spread.

In Vanua Levu these siliceous rocks and minerals are in places abundant. They are especially frequent on the surface of the extensive low plains on the north side of the island which constitute the basins of the Sarawanga, Ndreketi, Wailevu, and Lam-basa rivers ; but it is in the low-lying district of Kalikoso, in the north-eastern part, that they exist in the greatest quantity. They do not occur usually at greater elevations than 300 feet, and are found as a rule at much lower levels.

It must be understood that reference is not here made to quartz-veins, such as are found in certain localities and of which mention is made on pages 106, 116. It is not with the ordinary products

¹ *Reisen auf den Viti-Inseln*, as quoted on p. 22.

² *Petrographie des Viti-Archipels*, quoted on p. 293.

³ See work quoted on p. 378.

⁴ *Solomon Islands and their Natives*, by H. B. Guppy, p. 78.

of contact or general metamorphism that we have here to deal ; but with the remarkable surface-collections of silicified corals, nodules and flints of chalcedony, fragments of white quartz-rock, bits of jasper, and certain curious siliceous concretions, that occur often in association with fragments of limonite in these low-lying regions. All the siliceous materials above named have, as the microscope indicates, a common character, chalcedonic silica in a greater or less degree being the basis of all of them, whether coral, flint, white quartz-rock, or jasper. It soon became apparent whilst examining these districts that one general condition prevailed whilst this extensive deposition of silica and the formation of the beds of limonite were in progress. It cannot, however, be pretended that these processes are actually in operation on the plains now. Except in the case of the limonite in a few localities the processes have been suspended ; but they were in active operation not long ago : and an examination of the general characters of the districts will probably disclose some of the conditions under which these products have been formed.

On the surface of the Kalikoso plains, where these materials are most abundant, we find silicified corals associated with fragments and nodules of chalcedony, flints, white quartz-rock, limonite, concretions of carbonate of iron, &c., in the low-lying and often swampy district around the fresh-water lake, the whole region being only elevated between 20 and 60 feet above the sea. This is an area of decomposing acid rocks (quartz-porphyrries, trachytes).¹ On the other hand in most of the regions where these materials occur on the surface we have areas of basic rocks (basalts and basaltic andesites) incrusting in places with submarine tuffs and foraminiferous clays, the volcanic rocks undergoing extensive disintegration. Such for instance are the Lekutu, Sarawanga, Ndreketi, and Lambasa plains. In the Lambasa plains, which are described in this connection on page 139, we find besides the corals and flints and nodules of chalcedony, fragments of jasper. In the Sarawanga and Lekutu lowlands, we find silicified corals and limonite ; but here the crystallised silica of the corals contains a large quantity of water, whilst in its lesser degree of hardness and in its low specific gravity it comes near to semi-opal. In these and other localities, as in the level country around Ndranimako on the right side of the Yanawai estuary, we find curious concretions of the same kind of hydrous silica more or less crystalline. These concretions are described below.

¹ The region is described on pp. 224-228.

It may be remarked that nearly all the districts in which the silicified corals and concretions, siliceous minerals, and limonite occur, are scantily vegetated "talasinga" lands¹ with reddish soil. Except in the instance of the Kalikoso plains, the swamps and lakes have as a rule long since disappeared, their sites being alone indicated by the limonite on the surface. In the Mbua plains, however, there are occasional small ponds and swamps, and there is no doubt that the limonite so bountifully represented on the dry districts is still in process of formation.

Before drawing some general inferences as to the conditions under which this deposition of silica and iron took place, I will refer to the characters of the materials thus produced.

The silicified corals include massive corals of the *Astræan* and "Porites" kinds and branching specimens of the *Madrepore* type or habit. The former are rarely larger than 7 or 8 inches across and are merely fragments. The latter are always portions of branches, never exceeding 3 or 4 inches in length. In the last case it is sometimes possible to show, as in the case of a specimen found on the Kalikoso plains, that before silicification occurred the dead fragment of branching coral had been extensively eroded by solvent agencies and had been penetrated by burrowing molluscs. The larger blocks of massive corals have usually been extensively chipped by the natives in obtaining flints. In past times they were carried from one place to another, the result being that occasionally they were brought to me in the mountain-villages, all showing evidence of their having supplied flints to a past generation.

These corals are as a rule completely silicified. When a massive specimen is broken across it is not infrequently found that whilst the coral structure is preserved in its outer part, the inner portion is composed of a compact seemingly structureless mass of bluish-white or pale-grey flint, which has the characteristic microscopical appearance of chalcedony and a specific gravity of 2.59.² It is from the more compact parts of the silicified massive corals that the "worked" flints found on the surface were obtained, though in some of them, as in the case of a "scraper" in my collection, the traces of coral structure are still apparent to the eye. Wichmann observed in the case of the silicified corals from Fiji that the whole petrifying process appears to consist in the saturation of the coral with silica, the coral structure being usually

¹ For the meaning of "talasinga" see p. 55.

² The portion exhibiting the coral structure has a specific gravity of 2.54.

distinct, whilst the septa, often still calcitic, show the points of the calcite crystals projecting into the chalcedony which forms the mass. Lime however rarely occurs in the silicified corals of Vanua Levu. It was only in the case of one or two localities that the corals displayed any effervescence with an acid. In the microscope slide the massive specimens appear to be entirely of chalcedonic silica, the outlines of the cells and of the septa being indicated by ferruginous material. In a specimen of *Porites* by my side the crystallization of the silica has advanced beyond the chalcedonic stage and the coral is composed entirely of minute quartz-crystals, $\cdot 2$ to $\cdot 4$ mm. in size, often irregular, but sometimes forming doubly-terminated prisms. This has produced a somewhat crumbling rock, which is easily powdered by the finger; and in this case, therefore, the complete crystallization of the silica is resulting in the disintegration of the silicified coral.

The ordinary silicified massive corals of Vanua Levu, where the replacement by chalcedonic silica is complete, though the structure is preserved, have a hardness of about 6 and a specific gravity of 2.54, and yield but little water in the closed tube. Occasionally, however, as in the Sarawanga plains and in the Lekutu lowlands we find silicified fragments of branching corals which are easily scratched with a knife and have a hardness of 3 to 4 and a specific gravity of 2.3. The fractured surface is milk-white or reddish, and looks like semi-opal. When powdered and heated in a closed tube, the material loses one fourth or one fifth of its weight of water, the finest dust (passing away in the steam) being deposited on the sides of the glass. In the slide there is displayed a finely granular crypto-crystalline structure with in places a somewhat coarser quartz-mosaic, whilst chalcedonic quartz fills minute cracks in the mass. No coral structure is preserved. Numerous points coloured by iron oxide occur in the section, and minute dust-like inclusions abound, which are doubtless water-pores. I have described on a later page certain concretions found associated with these silicified corals which though formed of the same crypto-crystalline hydrous silica, are apparently silicified portions of nullipore-rocks.

The fragments of flint that occur commonly on the surface in these districts are, as above remarked, derived from the hard silicified coral-masses. Nodules of chalcedony, having all the appearance of having originated in cavities, are also very frequent. They may take the mamillary, agate, or onyx form, some of the agates when polished making beautiful specimens. These nodules

are of all sizes up to 3 or 4 inches across. Some of them are hollow and lined with clear quartz-crystals, whilst with others the cavity may be completely filled by interlocking quartz-crystals. The outer surface of one of the agates displays markings showing in relief casts of the "cups" of a minute-celled coral.

Mingled with the other siliceous materials on the surface of the Kalikoso and Lambasa plains are found fragments of a whitish quartz-rock, having a specific gravity of 2.53—2.57, being therefore markedly lighter than quartzite (2.63—2.67) which it somewhat resembles. It usually occurs as small hand-specimens; but in the vicinity of Mbatini-kama I found blocks, 12 to 15 inches across, lying in the river-bed. Under the microscope it displays a fine radio-globular aggregate of chalcedonic quartz.

Mention has already been made of the siliceous concretions, composed mainly of hydrous crypto-crystalline silica, which are associated with the silicified coral fragments formed of the same kind of silica on the surface of the plains of Mbua, Lekutu, and Sarawanga. They also occur in the Ndranimako lowlands on the right side of the Yanawai estuary, and in the more elevated inland districts of the Wainunu and Na Savu table-lands at elevations of 650 to 770 feet above the sea. They take the form of irregular nodules, or of flat uneven "cakes," usually two or three inches in size. They are as a rule reddish, but sometimes pink and white. Their hardness is only 3 to 4, and they are easily scratched with a knife; and when powdered and heated in a closed tube, they lose about one fourth of their weight of water. Under the microscope they exhibit a grey crypto-crystalline groundmass showing very finely granular crystalline silica with the cracks and small cavities filled with more brightly polarising chalcedonic quartz. But they differ as regards their other components and also in their mode of occurrence; and it is highly probable that the history of their origin is not always the same.

Those associated with the silicified corals on the Sarawanga and Lekutu lowlands show no structure in the slide that gives me a clue as to their origin; but they may perhaps represent old Nullipore nodules. Those around Ndranimako are coloured deep red; and whilst some give no indication as to their source, others are transitional in character, and display in the sections traces of the vacuolar semi-vitreous basic rock of which the original fragment was composed. The same red siliceous concretions form the pebbles and gravel in the stream-beds on the surface of the Na Savu table-land, 700 feet above the sea. These red flint-like

nodules of Ndranimako and Na Savu somewhat resemble the jasper of the island; but they are sharply distinguished by their microscopic characters, by being easily scratched with a knife, and by the large amount of water which they contain. Rolled stones, which were found in the shallow stream-courses on the surface of the Wainunu table-land 750 to 800 feet above the sea, exhibit in the sections, in spite of the general silicification of the ground-mass, the outlines of the original phenocrysts of felspar, and abundant skeletal magnetite rods, such as would characterise a semi-vitreous basic rock. It is evident that in the basaltic districts of the Na Savu and Wainunu table-lands these concretions have been formed under certain conditions by the decomposition of the silicates of basic rocks. But these conditions do not exist now; and I infer that the silicified rocks, which occur only in fragments on the surface, represent the silicification that occurred during the emergence of the land ages since.

Occasionally one comes upon in the mountain districts, as in the vicinity of Ndrawa, large solitary blocks 2 to 4 feet across of a whitish chert-like rock which has a hardness of 5 or 6, the harder variety having a specific gravity of about 2·58 and the softer, which yields a fair amount of water, a specific gravity of about 2·46. I noticed such solitary masses also on the Mbua plains. The first-named locality is dacitic and the last basaltic. They exhibit in the slides a patchy appearance, showing in some places finely granular crypto-crystalline silica and in others a coarser mosaic of chalcedonic quartz. Apart from the absence of any definite coral structure, I can only surmise that they were originally masses of reef-limestone. Their elevation even in the mountainous districts was not over 400 or 500 feet above the sea.

Fragments of jasper, which are associated with nodules of chalcedony and silicified corals in the Lambasa plains, are also to be found as pebbles and small blocks in the mountain streams of the Ndrawa, Ndrandramea, and Lea districts, together with bits of chalcedony and quartz-crystals. They do not occur, or are of rare occurrence, in the recently emerged Kalikoso district and probably belong to an earlier stage in the history of the island's emergence from the sea. They have a hardness of 6 to 7, not being scratched by a knife, and a specific gravity of 2·65 to 2·70; whilst but little water is given off in the closed tube. They are a variety of chalcedony, rendered opaque by the large quantity of red oxide of iron that it contains, and are really, therefore, iron-flints. The microscopical section in one case displays in the clear spaces a

beautiful globular aggregate, each globule having a nucleus of the iron oxide and giving a black cross in polarised light. In another case the globular structure is less perfect, and the chalcedonic groundmass is penetrated by a multitude of fine cracks filled with iron oxide.

The deposits of limonite vary in character in different localities, and evidently they have not all the same history. The soil of the low-lying plains around Wai-ni-koro and Kalikoso, and especially in the vicinity of the fresh-water lake, is often coloured a deep ochreous red. Small fragments of an earthy yellowish-brown limonite occur on the surface in quantity and are particularly abundant near the lake. They yield much water when heated. In some places in this district, as in the country traversed between Wai-ni-koro and Kalikoso, the surface is strewn with a number of small round concretions of the size of small marbles (6 to 12 mm.) which are composed of a mixture of carbonate of iron and limonite, but show no recognisable structures. They are somewhat friable and give off much water when heated, whilst they effervesce freely in hot hydrochloric acid. It is probable that some of the earthy limonite of the Kalikoso district contained originally iron carbonate and has been produced from concretions such as I have just described.

The variety of limonite found in fragments on the surface of the plains of Mbua, Lekutu, and Sarawanga, at elevations usually of 100 or 200 feet above the sea, is a heavy compact kind with a specific gravity of 3 to 3·5, and closely resembling red hematite. Since, however, it is lighter in weight and still contains a little water, it may be regarded as in the transition stage. It occurs as portions of cake-like masses varying usually from a third of an inch to rather over an inch in thickness. As a rule it is found in localities where no lakes or swamps now exist and may be associated, as in the Sarawanga and Lekutu plains, with silicified corals and siliceous concretions; but in some cases, as in that of the Mbua plains, ponds and swamps are still scantily represented in the vicinity, and the water of the stagnant streams is deeply coloured with iron (see page 56).

Ironstone gravel occurs in great quantity strewn over the surface of the basaltic table-lands, especially in the case of that between the Wainunu and the Yanawai rivers. The smaller gravel varies usually between one eighth and one third of an inch in size, the larger fragments being about an inch. The specific gravity is 3·1 to 3·2. The material forming the finer gravel dissolves with but little effervescence and scanty residue in hot

hydrochloric acid ; it gives off water and is evidently impure limonite. The larger fragments, 1 to 2 inches in size, represent the partial conversion into limonite of a basic volcanic rock with much glass in the groundmass which formed probably the surface of the basaltic flows of the plateaux. There must be an enormous amount of this iron-stone in the island. The finer gravel has a concretionary character, some of the pieces appearing like bits of stick that have been converted into limonite. It seems to have been formed during the disintegration of the rock on the moist surface of these densely wooded basaltic plateaux ; the process was not accomplished in ponds or swamps, but was carried out on ordinary damp ground.

It must be observed in the above connection that the soil in the areas of basalt and basaltic andesites, which occupy a large portion of the surface of the island, contains a large amount of fine magnetic iron-sand. After heavy rains the foot paths glisten with this fine material which has been washed out on the ground. This is especially the case in the extensive scantily vegetated "talasinga" regions where the basaltic rocks are disintegrating for a considerable depth. The river-sand of these areas, after a little washing, yields about 75 per cent. of magnetic iron grains which give in some cases a slight titanium reaction. The amount of magnetic iron-sand in these rivers, as for instance in the Yanawai and the Wainunu, must be very great. In the beds of the small sluggish streams on the surface of the Wainunu table-land the amount is also very large.

Any explanation of the origin of the extensive silicification evidenced by the occurrence of silicified corals and siliceous concretions on the surface in various parts of the lower regions of the island will have to include that of the formation of the limonite fragments so often accompanying them. The necessary conditions would, I think, be afforded by an emerging land-surface during the consolidation of the exposed calcareous muds and the subsequent draining of the new surface. On parts of the newly formed land, there would follow the successive stages of sea-water, brackish, and fresh-water swamps, such as are clearly indicated by the abundance of silicified coral fragments that strew the surface of the low-lying and often swampy districts around the fresh water lake of Kalikoso.

In such a locality as that of Kalikoso, there were no doubt at the time of the emergence large tracts covered with chalky calcareous mud derived from reef-debris ; and it was during the con-

solidation of this mud in the recently reclaimed area that the fragments of coral imbedded in it became silicified. In these cases where the imbedded corals were already much decayed, it is probable that the empty cavities thus produced were filled with silica, and that in this manner the nodules of chalcedony were produced. Here and there a pebble or a larger block of a volcanic rock would have been inclosed in the mud ; and in this case also silica largely replaced the original material of the stone. I imagine that with the evaporation of the water in the mud during the drying and consolidating processes the proportion of silica in solution would attain a degree of super-saturation and that the silicification would hence be brought about.

With the consolidation of the mud the deposition of silica ceased ; and in the case of any coral fragments, where the transformation was not completed, decay would often commence. In the instance of some bits of coral found imbedded in foraminiferous mud-rock in the Lambasa plains the process of the change had been suspended, and the fragments were in a state of decay, and coloured red by iron oxide. If silicification occurred in a submarine deposit only after it became a portion of an old land-surface we ought not to find incompletely silicified corals inclosed in it. For these reasons I do not consider that silicification would occur in the case of submarine deposits long after they have been raised above the sea.

On the other hand it would seem that the deposition of silica in the hard parts of dead organisms does not proceed in the shallow-water calcareous mud of coral reef coasts previous to emergence. Silicified corals have never as far as I know been found under such conditions. Nor could the coral fragments now lying on the Kalikoso plains, often only elevated some 20 or 30 feet above the sea, have undergone this change whilst exposed on the land-surface as they now lie. They must have been inclosed in some material containing abundant free silica ; and it is reasonable to suppose that this material was the chalky mud of the reef-flats on which they once lived. If this is admitted, then it follows that since, as above assumed, silicification does not occur in such a mud either before upheaval or long after it has been raised above the sea, it must take place in the intermediate period, or in other words whilst the recently exposed submarine deposits are consolidating and drying.

Several objections at once occur with reference to this explanation of the silicification of corals in this island ; but much more

investigation is needed to establish any view on the subject. In the Kalikoso plains, however, we have a critical locality for the pursuit of this inquiry. Concretions of carbonate of iron and deposits of earthy limonite are here associated with silicified corals on the surface of a level and often swampy district around a fresh-water lake in a region which is only elevated 20 to 60 feet above the sea. We are dealing here with an area of land that has emerged in comparatively recent times as far as the history of the island is concerned. The element of time is limited, and the problem is not complicated, as it would be in the case of an old land-surface, raised some hundreds of feet above the sea, by the intrusion of many other disturbing agencies. Nature has simplified matters here for the inquirer.

The evidence of recent emergence with regard to the whole island is discussed in Chapter II., and need not be again referred to here; whilst the general description of the Kalikoso district is given in Chapter XVI. In this connection it may be remarked that before their emergence the Kalikoso plains were covered by the waters of a large irregular sea-water lagoon or lake, which though more or less surrounded by hills had free communication with the sea on the north along the line of the passages now occupied by the Wai-ni-koro and Langa-lang rivers. Both massive and branching corals then thrived in the waters of the lagoon. There is no ground for supposing that during the emergence there was an intermediate stage characterised by brine-ponds and salt-swamps. The drainage from the slopes of the mountains to the southward would have prevented it. Whilst this change of level was in operation, brackish water collected in the deeper part of the original lagoon, forming a lake which as evidenced by the present distribution of limonite on the surface of the plains was then far larger than it is now. As the plains became exposed large flats covered with chalky mud in which dead corals were more or less imbedded were bared; and there and then as the drying and consolidation proceeded silicification took place in the manner before surmised. This deposit was of no great thickness, and has been since removed by the denuding agencies, whilst the silicified corals remain behind.

When in the Solomon Islands I was unable to find the source of the chalcedonic worked flints of such frequent occurrence in that region. In my general work on those islands (pp. 77 to 80) reference is made to this subject. It will probably be shown that there as in Fiji most of the flints are silicified corals.

In conclusion it may be remarked that those who object to the explanation of the origin of silicified corals advanced in this chapter will be able to find support for their alternative hypothesis in many facts detailed in these pages. Vanua Levu, for instance, abounds in hot springs; and Mr. Andrews might regard this fact as giving strength to his view that the silicified corals of Vanua Mbalavu in this group owe their condition to the agency of superheated water derived from volcanic rocks, more especially since hot springs are found on the island. Such an explanation could not, I think, apply to the extensive area of the Kalikoso plains where the silicified corals are associated with limonite on the surface of a recently emerged area. If these changes had been induced by hydrothermal action, one ought to find evidence of this in those localities in Vanua Levu where the hot springs issue from foraminiferous clay deposits, as in the vicinity of Vuni-moli; but no traces of such a transformation came under my notice. Wichmann does not advance any explanation of the silicification of the corals; but he considers that the "hornstones," which he obtained from Fiji, rocks corresponding to the chert-like rocks described by me on page 355, are the products of disintegration of the basic andesites. I have already pointed out that certain siliceous nodules have probably this origin. It is also likely that some of the jasper of Vanua Levu has been thus formed.

Note on a silicified Fern Rhizome.—This is a specimen, about three inches long, picked up by a native in a stream near Sueni in the centre of the island. It has the appearance of being a portion of the stem or rhizome of a tree-fern, and is permeated in its entirety by chalcedonic quartz, the fibro-cellular structure being still preserved. No other specimen of the kind came under my notice. The probability of the occurrence of silicified plant-remains in the pumice-tuffs of the Undu Promontory is pointed out on page 233.

CHAPTER XXVI

MAGNETIC ROCKS

THE literature on the subject of the magnetism of rocks is very extensive,¹ and even if I was capable of doing so, any attempt to deal generally with this complicated phenomenon would be out of place here. Zirkel in his characteristically thorough fashion has reviewed the subject in his general work on petrography, but since the date of the last publication of that book, 1893-94, the literature has been much increased and the subject has from time to time been opened up in scientific periodicals, occasionally in ignorance of the labours of those that have gone before. Here, the local magnetisation of rocks is alone considered, the general question of earth magnetism not being entered into.

According to Zirkel one of the earliest known observations of this phenomenon was made by Bouguer, the French geographer, whilst he was engaged in the measurement of a degree of the meridian in the vicinity of Quito in 1742. Alexander von Humboldt, however, was one of the first to attract general attention to this subject by the announcement of his discovery in 1796 of a

¹ A good list of references to the early German authorities on the subject is given in the *American Journal of Science and Arts* for 1831, vol. 20. . . . Zirkel in his *Lehrbuch der Petrographie* (1893, vol. i. p. 565) gives most of these and many more recent. . . . Harker in his paper below named refers to a review of the earlier literature in *Verh. naturh. Vereins.* Bonn, 1851, vol. 8, and to a more complete bibliography by Meli in *Boll. Soc. Geol. Ital.* 1881, vol. 9. . . . British Association Report in 1889 by Professors Rücker and Thorpe on the Magnetic State of the British Isles. . . . *Nature* for August and September, 1894, &c. . . . Harker on magnetic disturbances in the Isle of Skye, *Proc. Cambr. Philos. Soc.* vol. 10, part 5. . . . Skinner in *Proc. Cambr. Philos. Soc.* May, 1894. . . . Clark in *Journ. Roy. Instit.* Cornwall, 1890-93. . . . Folgheraiter in *Frammenti concernanti la geofisica*, Rome: referred to in *Nature*, July 27, 1899, and Nov. 8, 1900.

"great magnetic mountain" in the heart of Germany. He was then director-general of the mines in two Franconian principalities; and in order to awaken the interest of German physicists and mineralogists in this matter, he announced his discovery with an air of mystery, and did not disclose the locality for many months. He then placed his specimens in the mining-office at Bayreuth to be sold at so much by weight for the relief of poor miners. His plan succeeded, and this young savant who had yet before him his great career, had soon enlisted the interests of several of the noted scientific men in Germany, including Werner the mineralogist, Voigt the mathematician, Blumenbach the naturalist, Charpentier, and others. The amount of attention that this subject then excited can be inferred from the pages of the "*Intelligenzblatt der Allgemeine Literatur-zeitung*" for 1796-1797 and from the contemporary publications. It has been almost forgotten now, and the matter is indeed often approached "*de novo*."

However, although by these means the data became largely increased, no generally accepted explanation resulted. Opposing views continued at various times to be advanced; and it has only in recent years come to be recognised that the magnetic polarity¹ of rocks in exposed situations, as in the mountain-peak or in the crested spur, often arises from atmospheric electricity independently of the inductive action of terrestrial magnetism. This is the conclusion to which the later evidence given by Zirkel is directed and was that which Oddone and Sella formed from their study of the magnetic rocks of the Central Alps. It is not, however, always necessary to suppose that the affected rocks have been struck by lightning, although Sella and Folgheraiter have shown that this is the result of such a contact. They may be found, as indicated by Mr. Harker, in mountainous localities where thunderstorms are remarkably rare, and where the peaks act, it is suggested, as natural conductors. It is easy to show, remarks the same author, that no lapse of time is required for rocks in exposed situations to become magnetised. The stones of cairns erected a few years before on the mountain-tops of the Isle of Skye become invariably highly magnetic; whilst the loose stones lying on the ground display this property to a much less degree. Nor is it requisite that the rocks affected should be basic volcanic rocks. It

¹ Nearly all volcanic rocks at all basic are magnetic, owing to the constant presence of magnetite; but magnetic polarity, when the rock-fragment has a negative and a positive pole, is not directly concerned in volcanic rocks with the mineral composition.

has long been known that granites, trachytes, &c., can possess magnetic polarity¹; and the existence of this quality among acid volcanic rocks is well shown in the case of the dacites in Vanua Levu, rocks which compose some of the isolated mountain-peaks.

One finds occasional reference to the highly magnetic character of the rocks in oceanic islands of volcanic origin, but the nature of the property is not always described; and it is sometimes not possible to gather from the data given whether the magnetism affects the whole mountain mass, when it would be of the regional kind, due probably to induction, or whether it is the simple magnetic quality that almost all basic volcanic rocks possess on account of the fine magnetite disseminated through the rock, or whether there is evidence of a deposit of magnetite in the vicinity, or whether it is a mere surface phenomenon confined to the bare rocks of peaks and ridges, when such rocks, whether gabbro, granite, basalt, trachyte, or dacite, display magnetic polarity. Dana, with regard to the basaltic mountain of Tahiti, remarks that the compass was often rendered useless by the local attraction of the rocks, bearings taken being found to vary two to three points on changing the position of the instrument.² Major Haig says that the compass becomes perfectly useless anywhere in the neighbourhood of one of the mountain-masses or extinct craters in Mauritius, and attributes this effect to the magnetite in the basalt.³

On the summit of Mauna Loa in Hawaii, at the edge of the great crater and in the vicinity of the site where Commodore Wilkes carried out his pendulum observations in 1840, I found my compass-needle greatly affected by local attraction, but I neglected to inquire further into the matter. Judging from my sojourn of twenty-three days on this mountain-top, thunder-storms are of very rare occurrence there; but the electric condition of the air is at times very evident, and its physiological effects are somewhat distressing. My blanket at night crackled in my hands and emitted sparks, so that I could trace with my finger the letter A in phosphorescent hues on its surface.

That lightning is directly responsible in some instances for the magnetic polarity of rocks in mountain-peaks is also well established. It has been illustrated in an indirect fashion only last year in the disaster on the Wetterhorn. Rocks partially fused by thunderbolts and displaying polarity occur on the summit of the

¹ Some of the earliest observations were made on granites and trachytes.

² *Geology of the United States Exploring Expedition*, 1849, p. 294.

³ *Quarterly Journal Geological Society*, vol. li., p. 469.

Riffelhorn and on one of the peaks of Monte Rosa, and fulgurites have been also obtained from Mont Blanc. . . It is not always easy to explain, however, isolated cases of polaric rocks where no signs of fusion occur. Whilst descending into the Valle del Bove from the Etna Observatory, I picked up four small volcanic bombs of basic lava, of which one displayed polarity, the poles being situated at the sides of the bomb. Zirkel quotes the observation of Naumann on the summit of the volcano of Moryoshi in Japan. Here out of a number of lava-blocks lying about only one exhibited marked polarity, whilst the rest showed no signs of it.

Before dealing with the polaric rocks of Vanua Levu, I will refer to two localities in other parts of the group where magnetic rocks have been observed. During the Wilkes' expedition in 1840,¹ Lieutenant Underwood observed great local attraction at Naikovu, a rock 90 feet high of volcanic formation lying off the south end of Nairai Island. He found a "deviation" of $13\frac{1}{4}$ points (149 degrees) at the top of the rock, whilst at the foot near the water the needle gave correct bearings. In the *Sailing Directions for the Pacific Islands*, published in 1900, the "deflection" at the summit is said to be 87 degrees. It is stated by Mr. Eakle in his paper (quoted on p. 293) on the rocks collected by the recent Agassiz expedition that this rock is composed of an augite-andesite. . . . I have learned from Mr. Alex. Barrack that there are some highly magnetic rocks on the west coast of Viti Levu in the vicinity of Likuri Harbour in the Nandronga district. It is said that specimens sent down to the colonies were found to contain 95 per cent. of magnetite.

It is very probable that the results obtained by me for Vanua Levu can be generally applied to the other large islands of the group. The observations were made during my various geological journeys and deal only with certain aspects of this interesting subject.

The first feature in this connection is the frequency with which simple magnetism is displayed by the acid as well as basic volcanic rocks of this island. About 95 per cent. of the volcanic rocks collected attract both ends of the needle.² This property of volcanic rocks is well known, and is to be attributed to the mag-

¹ Wilkes' *Narrative of the U.S. Exploring Expedition*, iii., 185.

² Of the tuffs and clays, almost all submarine and often containing tests of foraminifera and sometimes molluscan shells, about 90 per cent. exhibit simple magnetism in a slight degree, but out of nearly 100 specimens tested none show polarity.

netite in the groundmass.¹ On examining the character of the non-magnetic rocks it appears that almost all belong to two groups where magnetite might be expected to be scanty. The first includes the pitchstones or basic glasses, sometimes fresh, at other times more or less palagonitised. The second comprises the highly altered basic rocks, where the ferro-magnesian silicates have been replaced by viridite, calcite, and pyrites. It is not, however, to be implied that rocks of these two kinds will not sometimes attract the needle. Many do not, and those in my collection that do so act feebly.

Coming to the magnetic polarity displayed by some of these rocks, when the ordinary hand-specimen behaves like a magnet in attracting one pole of the needle and repelling the other, it is to be at first observed that a rock can become polaric without being previously magnetic. Dr. Folgheraiter has observed polarity in the case of fragments of ancient bricks and pottery; and he has described the same effect in the masonry of a house struck by lightning. In one or two of the Vanua Levu acid rocks showing polarity this can be also premised since magnetite is present in very slight degree.

Polarity is very frequent among the volcanic rocks of this island. Out of 520 specimens in my collection, which was made without any reference to this matter, 80, or 15 per cent. are polaric. Of these seven-eighths are basic and the rest are acid rocks; but this proportion is partly accounted for by the far greater prevalence of basic rocks in the island. The basic rocks showing polarity include some of the heaviest olivine-basalts with a specific weight of 3.0, as well as some of the lighter augite-andesites with specific weight of 2.7. They comprise the coarse textured dolerite as well as the vitreous pitchstone and include both scoriaceous and amygdaloidal rocks. The polaric acid rocks are mostly referable to the dacites, with a specific gravity of 2.5 to 2.6.

Humboldt remarked long ago that there is no direct relation between the degree of polarity and the specific weight. This is well brought out in the table subjoined; but it should be at once observed that there is an indirect relation. Although when we arrange the rocks in a series according to their specific weight we find no corresponding relation in the amounts of the polarity, we observe that the extent to which polarity can be developed is markedly greater in basic than in acid rocks. From this it may be

¹ On p. 357 will be found some notes on the magnetic iron sand that occurs in great abundance in river and stream beds.

inferred that the degree of intensity of the exciting cause required to give polaric powers of a certain value to an acid rock, like a dacite, would be much greater than that necessary to endow a basalt with equal powers. We should not expect to find the same amount of polarity in the bare rocky peaks of two adjacent mountains, where one was of dacite and the other of basalt ; and, other things being equal, if two mountains had been exposed for ages to the same conditions, we should regard the polaric powers of the two as nature's equivalent values for the work of atmospheric electricity, on the two rocks in question. We have two such mountains in Vanua Levu in the case of the adjacent peaks of Ngaingai (2,448 feet) and Navuningumu (1,931 feet) which are about $2\frac{1}{4}$ miles apart and possess similar bare rocky pointed summits. I take it that the polaric power of 25° of the dacite (sp. gr. 2.57) in the first case is equal to the power of 90° of the basaltic andesite (sp. gr. 2.82) in the other. In the dacitic peak of Ngaingai and in the basaltic peak of Navuningumu we can measure what work atmospheric electricity can accomplish in the course of ages in the magnetisation of rocks. The other conditions being taken as about the same, the main determining difference is to be found in the rock-characters.

In the table on the opposite page we have a series of volcanic rocks placed according to their specific weights, which range from 2.5 to 3.0, and in the second column are shown their relative polaric powers as indicated by the number of degrees the north end of the magnetic needle is repelled by the corresponding pole in the hand-specimen. For this purpose a magnetic needle $2\frac{1}{2}$ inches in length (strictly speaking 6.5 centimetres) was employed, a card marked in degrees being placed beneath. The north pole of the stone was placed in contact with the north end of the needle, and after the needle had become stationary in its new position a reading was taken.

These polaric rocks came under my notice over most of the island. They are infrequent in the district between Undu Point and the Wai-ni-koro River, where, however, acid tuffs are largely exposed ; and I did not find them in the Natewa Peninsula east of Lea, their absence from my collections made in the Mount Freeland range being remarkable. But it is probable that this is due to the surface conditions, since dense wood covers the slopes, and bare rocky peaks are rarely to be seen.

With regard to the influence of locality on the occurrence of polaric rocks, the results may thus be classified. About one-third

are found in the exposed rocky peaks of hills and mountains. Another third are found where the rocks are bared in headlands, coast cliffs, inland-bluffs, ridge-tops, and in the open basaltic plains where trees are scanty. On the other hand, a third occur in situations, as in wooded districts where the rock exposure is scanty, when it is not easy to explain the polarity, unless it was developed in clear districts that have since become covered with forest.

Table showing the Relation between the Specific Gravity and the Polarity of Volcanic Rocks.

Character of rock.	Specific gravity.	Amount of polarity. ¹
Dark olivine-basalt	3'00	10°
Grey " "	2'94	29°
" " "	2'92	7°
Dark " "	2'90	10°
" " "	2'87	30°
Basaltic andesite	2'82	90°
" " "	2'77	5°
Pyroxene-andesite	2'72	38°
Dacite	2'61	17°
"	2'59	5°
"	2'57	25°
"	2'50	14°

In no place did any evidence of the direct action of lightning come under my notice. Mr. S. Skinner who kindly looked at a few of these rocks says that he found no trace of fulgurites in them. It is probable that here as in the mountains of Skye, as described by Mr. Harker, these effects are the result of the general influence of atmospheric electricity independently of the direct agency of lightning. The frequency of polaric rocks in the highest peaks of the island is very remarkable. Generally speaking, all the bare summits of the mountains are polaric. In my experience there is no exception. All the rocks obtained from the actual summits show polarity. The variety of rocks thus affected is suggestive; and this chapter may be concluded with a brief reference to their mode of occurrence on some of the mountain-peaks.

In Mbatini, 3,437 feet in height, which is the highest mountain of Vanua Levu, the pyroxene-andesite of which the bare rocky peak is composed is somewhat weathered and has a polaric or

¹ These values represent the number of degrees that the magnetic needle is repelled. The method is described above. A note on the average amount of polarity found in all my polaric rocks is given at the end of the chapter. The term "dacite" is here an equivalent of "felsitic andesite."

repellent power of 28° . Specimens of rock obtained below the top show no polarity, the mountain being well wooded except at the summit. In the adjacent mountain of Koro-mbasanga,¹ the polaric rocks are limited to those exposed in the peak which is bared of vegetation. The rocks in question are tuff-agglomerates, the small blocks of pyroxene-andesite standing out from the tuff having a polaric force of 14° or 15° . This effect has been produced in greatest intensity in the isolated peak of Navuningumu (1,931 feet) in the Ndrandramea region. Here the bare summit is formed of a semi-vitreous, slightly vesicular, basaltic andesite with a specific gravity of 2.82 in its present condition.² This rock is powerfully polaric, and rendered the compass useless, the deviation generally to the westward varying from 20° to 50° . I place its repellent force at about 90° , hand specimens affecting the magnetic needle at a distance of 13 or 14 inches. None of the various rocks obtained from the wooded slopes below displayed polarity.

The neighbouring mountain of Ngaingai is composed entirely of dacite having a specific weight of 2.57. The highest point of the summit, 2,448 feet above the sea, is bare and rocky, and the stone here is markedly polaric, the repellent force being about 25° . Specimens from the lower wooded slopes show no polarity. Near by rises the hill of Ndrandramea, which is composed in mass of acid andesites or dacitic rocks. The summit (1,800 feet) is scantily vegetated, and here the somewhat weathered rock which has a specific weight of 2.44 (probably near 2.5 in the fresh condition) has a polaric force of 14° . Specimens of a more compact rock taken from the wooded slopes 300 feet below the summit (sp. gr. 2.58) and from 700 feet below the top (sp. gr. 2.68) showed no such effect; but a specimen taken from a mass of agglomerate in the last locality repels the needle 12° . Its specific gravity is 2.61, and no doubt the mass had been originally a portion of an exposed cliff-face.³

The summit of Mariko (2,890 feet), the Drayton Peak of the chart, is formed of a rubbly agglomerate of a compact basic andesite.

¹ This name has been wrongly applied in the Admiralty chart to the mountain of Mbatini. Koro-mbasanga, 2,500 feet, lies three miles to the north.

² This rock is described on p. 109. There is no exceptional development of magnetite for a basic rock in the groundmass.

³ Unfortunately, I have no data for the peaks of Na Raro and Vatu Kaisia, except that specimens obtained below the summits are non-polaric. In the case of Na Raro I did not retain the specimen obtained at the top; whilst in my ascent of Vatu Kaisia I did not quite reach the summit.

Though it displays bare rock-faces, the actual peak has a soil-cap at least 18 inches deep and supports small trees and shrubs. Notwithstanding this, I found when standing on the peak that my compass was very noticeably affected, the pull being to the eastward, whilst the amount of deviation increased from 11° to 16° when changing from the sitting to the standing position. Specimens of blocks from the agglomerate forming a rock-face 10 feet below the summit possessed polaric powers of 12° and 5° . Others of the same rock exposed in a cliff-face 450 feet below had a weak repellent power of only 4° . . . As in the case of Mariko, the top of Thambeyu (2,700 feet) is vegetated; and beneath the smaller trees blocks of polaric rocks lie on the surface. One of these, a pyroxene-andesite (sp. gr. 2.72), from which I obtained a specimen, has a polaric power of 38° . In another case, that of an amygdaloidal rock of the same character, the repellent power is 14° .

I might mention several other polaric peaks, but it will be sufficient to refer to one or two other localities. In the mountainous basaltic district around Solevu Bay the peaks are usually polaric. Specimens from the top of Uli-i-matua, 1,100 feet, have a repellent power of 15° . The three-peaked hill of Koro-tolu-tolu appears to be in the mass of polaric basalt from the foot to the summit, having a repellent power varying from 4° to 30° , the most active specimens being obtained from the lower slopes, which, however, are scantily covered with trees. Samples of the grey basalt from Koro-i-rea show polaric powers of 3° to 7° .

As examples of the numerous lesser hills with bare rocky polaric summits I will first take Bare-poll Hill facing Soni-soni Island. This hill is only about 150 feet above the sea, its top being formed by two large masses of a basic andesite lava with a glassy groundmass, incrustated with agglomerate, the whole representing a volcanic "neck." A specimen of the rock masses has a repellent force of 22° . Another instance is afforded by Vatui, a hill 450 feet in height situated south of Mount Sesaleka. Its summit is capped by a naked mass of tuff-agglomerate pierced by a dyke 18 inches thick of an olivine-basalt, with a specific gravity of 2.90 and a polaric power of 10° .

A somewhat suggestive example is afforded by the hill of Na Suva-suva, 1,110 feet high, which overlooks Naindi Harbour to the east of Savu-savu Bay. It is only occupied by trees in its upper part, and a specimen of the olivine-basalt, of which the hill is composed, that was obtained from the wooded summit, shows no polarity; whilst another from the slopes, two-thirds of the way up,

which had been cleared of trees, has a repellent force of 10° . The polarity of the olivine-basalt from the well-wooded slopes of Ulu-i-ndali, a range 1,100 feet in height on the east side of the Wainunu estuary, is not so easily explained; the intensity varies from 8° to 28° . Ngatau-levu, a hill 1,650 feet in height, rising behind Lea on the south coast of Natewa Bay, is polaric in its upper portion. Specimens of a hemicrystalline basic andesite, somewhat scoriaceous, which form the agglomerate of the rocky summit, have a repellent force of 18° , whilst a similar rock from the agglomerate of an exposed spur two-thirds of the way up the hill has a force of as much as 38° . A curious case of polarity is exhibited in a bare tuff overlooking the Vui-na-Savu River between Rauriko and Vitina. It is composed of a much weathered whitish trachytic rock, which in appearance affords no promise of polarity, but has the power of repelling the magnetic needle 2° to 3° .

Note on the Average Polarity (Repellent Power) of the Volcanic Rocks of Vanua Levu.

It would appear from the table given below that the difference in the average polarity of acid and basic rocks is not very great. The average for rocks with a specific gravity below 2.7 is about 10° ; and that for heavier rocks is about 14° . The difference mainly lies at the maximum end of each series, the capacity for extreme polarity being, as before remarked, markedly greater in the basic rocks.

Specific gravity.	Character of rocks.	Number of specimens.	Polarity. ¹	
			Range.	Average.
2.50-2.59	Dacites	6	2° - 25°	11.6°
2.60-2.69	Dacites and augite-andesites	5	3° - 16°	8.6°
2.70-2.79	Augite-andesites	5	5° - 38°	13.2°
2.80-2.89	Basaltic andesites and olivine-basalts	18	3° - 90°	15.0°
2.90-3.00	Olivine-basalts	14	3° - 29°	12.7°

¹ The mode of measurement is described on p. 366.

It is, however, noteworthy, as indicated by the value of the average in each series that not one of them is a good series. They form curves which in each case present an extreme maximum variant which is suggestive of quite another degree of magnetising agency. This is also illustrated in the combined curve of all the results given above. The acid as well as the basic series are thus characterised, and the extreme maximum variants are in each instance afforded by the highest mountain peaks. It is probable that there is an accelerating ratio of magnetisation with increased elevation. However that may be, it appears evident from my observations on the two adjacent peaks of Ngaingai and Navuningumu that the limits of polarity acquired through atmospheric electricity without the direct action of lightning would be, as measured by the scale here employed, four times as great for a dacite (25°) as for a basaltic andesite (90°).

CHAPTER XXVII

SOME CONCLUSIONS AND THEIR BEARINGS

VANUA LEVU is a composite island built up during a long period of emergence, that began probably in the later Tertiary period, by the union of a number of large and small islands of volcanic formation representing the products of submarine eruptions. It differs in this respect from Viti Levu which is much more massive in its profile and possesses a greater proportion of plutonic rocks. When, however, Viti Levu comes to be systematically examined, it is likely that traces of its composite origin will be found. The evidence seems to show that it is older than Vanua Levu ; but they are both situated on the same submarine platform, the area of which is nearly equal to the combined areas of the two large islands that rise from it.

This platform, as indicated in the small plan of the group, is limited by the 100-fathom line in the charts ; but since the reefs on their seaward slopes plunge down precipitously, such a line practically serves to delineate the margin of the plateau. It has been my object to show on previous pages¹ that this submarine platform is a basaltic plateau built up by submarine lava-flows and incrustated with coral reefs and their deposits. It has been pointed out that this platform passes gradually, as it proceeds landward, into the low-lying basaltic plains that constitute the sea-border in the western part of the island, where the breadth of the submerged plateau is greatest. The basaltic flows of the plains often display the almost vertical columns of slightly inclined flows. Their apparent termination at the sea-border, where they are in places covered over with submarine deposits, cannot, however, be accepted as their real limits. According to my view they extend several

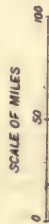
¹ See pp. 2, 15, 18, 56, 62, 72, &c.

FIJI ISLANDS.

FROM ADMIRALTY CHART 780, CORRECTED TO 1901.

ALL DEPTHS BEYOND 100 FATHOMS ARE COLOURED BLACK.

HEIGHTS IN FEET, DEPTHS IN FATHOMS.





miles seaward and form the platform, as is shown in the sections on pages 62 and 107.

We have in the great basaltic mountain of Seatura, which forms the bulk of the western end of the island, a probable source of many of these basaltic flows; and the occurrence inland in the western half of Vanua Levu of elevated table-lands of basalt like that of Wainunu, which extend from the centre of the island to near the coast, afford testimony that the formation of these flows extends over a considerable period of the island's history.

It is held by Professor Agassiz that these submarine platforms are the work of erosion into the flanks of the up-heaved islands.¹ In Chapter II. it has been pointed out that the eroding agencies are not actively in operation in our own day, and that there is good reason for the belief that the process of amalgamation by which Vanua Levu has been built up during a prolonged period of emergence, is not suspended at the present time. It is assumed that the uniformity in Nature's methods has not been broken. If, however, we have here platforms of erosion, the coasts of Vanua Levu, as far as my interpretation goes, supply no evidence of it; and we have to imagine that a period of emergence extending over a geological age has been followed by a similarly vast period of erosion without much change in level.

Whatever agencies have been at work, the production of submarine platforms 10 to 20 miles in width must have been a stupendous operation; and we shall be obliged to inquire whether plateaux, either submarine or upheaved, occur in association with volcanic islands in other parts of the world, and under what conditions they have been formed. At least four hypotheses have been framed with regard to the submarine platforms of Fiji. There is first the original theory of subsidence of Darwin; but Vanua Levu, which presents one long story of emergence, offers nothing to support this view. There is the growth of a reef seaward on its own talus, as advanced by Murray. There is the theory of erosion of Agassiz. There is lastly my own idea of basaltic plateaux incrustated by reefs. We may therefore inquire as to the evidence afforded by Vanua Levu in favour of these views. Basaltic flows, in places covered by submarine deposits, form the low plains at its sea-border, where the platforms are broadest; and there rises a basaltic mountain of the Mauna Loa type, occupying most of the western end of the island. No one would be bold enough

¹ *The Islands and Coral Reefs of Fiji*, Bull. Mus. Comp. Zool. Harv. Coll. vol. 33, 1899.

to place the limit of these basaltic flows at the water's edge ; and as is indicated in the sections, they probably extend for miles under the sea.

If we look for an island which in its extensive palagonite-formations, in its basaltic table-lands and later basaltic flows, in its huge mountain-ridges, and in its evidence of submergence, most resembles Vanua Levu, we seem to find it in Iceland. It is in Iceland, I think, that we must expect an explanation of many of the puzzling features in the structure of Vanua Levu.

I pass on now to refer to some of the general points in the geology of this island, which have been dealt with in detail in the earlier chapters of this work. With regard first to the distribution of the volcanic rocks, it may be remarked that my materials do not lend themselves to making a geological map. The most comprehensive idea of the principal points in the geological structure will be obtained by reading the description of the profile given in Chapter I. There is, however, a method in the distribution of the rocks that may be again noticed here. The plutonic rocks are very scantily exposed, as is shown on page 249 ; and they are not displayed at all in the western half of the island. The more basic eruptive rocks, the olivine-basalts and basaltic andesites, are mainly confined to the western half, that is, west of Nanduri on the north and of the Ndreke-ni-wai River on the south. Ordinary augite-andesites occur also in the western half ; and together with the hypersthene-augite-andesites they are found over most of the rest of the island, excluding the north-east portion, east of Lambasa and Tawaki, where quartz-porphyrines, oligoclase-trachytes, and acid pumice tuffs prevail. The acid andesites, including the hornblende-andesites and the dacites or felsitic andesites, are best represented in the Ndrandramea district in the midst of the basic rocks. They occur in the isolated peaks of Na Raro and Vatu Kaisia and in one or two other localities, as in the Valanga Range and on the shores of Natewa Bay in the vicinity of the Salt Lake. These peaks of acid andesites, as in the instances of Vatu Kaisia and Soloa Levu, are at times in part overwhelmed or surrounded by the basaltic flows. This singular feature of bosses of acid rocks in the midst of basaltic fields offers another point of resemblance between Iceland and Vanua Levu.

The mountain-types vary considerably, the ridge-mountains, however, being most characteristic of the island. The basaltic mountain of Seatura, though its lava-flows were evidently in the main submarine, belongs as before observed to the Mauna Loa

type. In its radiating valleys and gorges and in other characters it recalls the description given by Dana of the island of Tahiti. The peaks of acid andesites, represented in the isolated hills and mountains of the Ndrandramea district, and in the solitary mountains of Vatu Kaisia and Na Raro, are the necks and stumps of submarine volcanoes dating back to the pre-basaltic period of the island. It is, however, in the great mountain-ridges of the central portion of the island, those of Va Lili, Korotini, Nawavi, Thambeyu, Mbatini, Mariko, &c., that we find, as just remarked, the most typical features of the internal topography of Vanua Levu.

Agglomerates overlying palagonite-tuffs and clays, that are usually foraminiferous and sometimes inclose molluscan shells, clothe the slopes of these mountain-ridges up to elevations of 2,500 feet and over above the sea. Most of these great ridges, now more or less covered over by these submarine deposits, represent lines of submerged vents, of which only a few raised their summits above the sea in the earliest stages in the history of the island. At this early period there were no coral reefs. Some of the ridges present a marked parallel arrangement, recalling the arrangement of the mountain-ridges and lesser chains of hills as described by Dr. Johnston-Lavis in the account of his visit to Iceland.¹ The description of Hekla (as given by Thoroddsen) as "an oblong ridge which has been fissured in the direction of its length and bears a row of craters along the fissure,"² comes very near to my conception of the original condition of these great mountain-ridges before the emergence. Dr. Johnston-Lavis sees in Hekla a type of volcanic mountain very different from that of Vesuvius and Etna. He regards it as a ridge marked by a number of parallel ridges and furrows, and built up along a main fissure with a number of subsidiary parallel fissures.

The part taken by palagonite in the composition of the finer deposits over the greater portion of Vanua Levu is another prominent characteristic of the island. Palagonite, as I have suggested in Chapter XXIV., is formed probably on the surface of submarine flows of an ophitic basaltic rock.

The age of the more recent of the deposits of this island, the fossiliferous tuffs, the pteropod-ooze rocks, and the foraminiferous muds, cannot be far different from that of the same deposits in other parts of the group, since it is apparent that the same general

¹ *Scott. Geogr. Mag.* 1895.

² *Ancient Volcanoes of Great Britain*, by Sir A. Geikie, 1897, ii. 260.

movement of emergence has affected both of the two larger islands. Professor Martin of Leyden informed Dr. Wichmann that the fossil shells found in the tuffs of Viti Levu, Ovalau, and other islands were Tertiary but not older than the Miocene.¹ Dr. Dall, after examining the fossil mollusks collected by Professor Agassiz from the elevated limestones of Fiji, confirmed the impression formed by the latter as to their late Tertiary age. None of the genera were extinct, and the fossils were in his opinion younger than Eocene and either Miocene or Pliocene.² The Rev. J. E. Tenison-Woods described as extinct Tertiary fossils, some corals and mollusks from the interior of Ovalau.³ Mr. H. B. Brady, basing his conclusions on the character of the foraminifera, assigned a Post-Tertiary date to the Suva "soapstone" taken at elevations up to 100 feet in that neighbourhood.⁴ Professor David referring to some fossil teeth of Carcharodon and to a fossil Tridacna found at Walu Bay infers that the deposits are at least as old as Pliocene but not as old as the earlier Tertiaries.⁵ Since, as pointed out by Professor David, the latest movements of emergence have taken place in recent geological time, these various observations go to show that whilst the latest exposure of deposits has occurred in recent time the mass of the fossiliferous deposits date back to the Pliocene and the Miocene periods.

According to Wichmann these islands were in a continental condition during the Palæozoic and Mesozoic periods, and it was only in the later Tertiary age that the movement of subsidence began that prepared the way for the formation of the more recent deposits. The submergence during the Tertiary period and the subsequent emergence are facts that cannot be gainsaid; but we may ask where is the evidence of the continental condition during the earlier periods. There is little in the results obtained from Vanua Levu that directly supports such an hypothesis. Under such circumstances one ought to have discovered in the deposits of this island some evidence of this early condition, and there should be found in the fauna and flora some traces of the original organisms. According to Hedley there is some indication of a continental condition in the molluscan fauna, and he quotes

¹ See Wichmann in *Min. und Petrog. Mitth.* band v. heft 1.

² *Amer. Journ. Sci.* VI. 165, 1898. See also Agassiz on the *Islands and Coral Reefs of Fiji*, before quoted.

³ *Proc. Linn. Soc. N.S.W.* 1879-80, p. 358.

⁴ *Quart. Journ. Geolog. Soc.* vol. 44, 1888.

⁵ See Preface to the report of Mr. Andrews quoted on a later page.

Fairmaire as regarding the Coleoptera as of a continental character ; but no one, that I am aware of, has found any direct evidence of the Pre-Tertiary periods in this group. It is in harmony with the geological characters to assume that these islands made their first appearance during the Tertiary epoch.

Coming to the subject of the movements whether of land or sea that led to the appearance of these islands, we shall not be begging the question if we speak of their "emergence." There is no doubt as to there having been during and since the Tertiary epoch an emergence of some thousands of feet, allowing for the original depth of the foraminiferous deposits now found at elevations of over 2,000 feet above the sea. In Chapter II. it is shown that there is good ground for the belief that these changes of level have not altogether ceased. Of what nature, we may ask, is this movement. We have before us the grand conception of Suess that the emergence of the land in the different phases of geological time has been produced by the general lowering of the level of the ocean arising from local subsidences of the earth's crust. This view in the case of the recent calcareous formations of the Pacific is applied to the terraces of the Loyalty Islands ;¹ and it follows that it is also applicable to the elevated calcareous deposits of the islands of the Western Pacific as a whole, as in the case of the Tongan Islands, the New Hebrides, the Solomon Group, &c. Such a general change of level ought to be represented in the large island of Hawaii in the North Pacific, since it could not be confined to one locality in this ocean. There is no evidence of emergence, as far as I know, presented by this island. During my sojourn there, I examined much of its coasts. Now the antiquity of the flora of this group is sufficiently attested by the circumstance that it ranks first among the oceanic groups of the Pacific for the number of endemic plants that it possesses ; and the same conclusions may be drawn from the insects and the birds. There is no evidence in this group, one of the most ancient of the Pacific archipelagoes, of that great movement of emergence, which is abundantly demonstrated over the Western Pacific.

The standpoint is therefore taken that the movement of emergence which began in the Tertiary period and is probably still in operation is confined to the southern portion of the tropical Pacific. Speaking of the time of the Fijian emergence, Professor Agassiz observes that "it is not unnatural to assume that it was coincident with the elevation of Northern Queensland, and that the

¹ *Das Antlitz der Erde*, French edition by E. de Margerie, ii. 534.

area of elevation included New Guinea, the islands to the east of it as far as New Caledonia, and as far east as the most distant of the Paumotus, and extended northward of that line to include the Gilbert, Ellice, Marshall, and Caroline Islands."¹

From the report of Mr. Andrews² it is evident that in the Lau Islands of the Fiji Group volcanic outbreaks have taken place since the last upheaval. He describes in the case of Mango and other islands the manner in which cliffs of limestone form inliers in flows of andesitic lava. In the history of these islands he first distinguishes the period of calcareous deposits, when the bedded limestones forming the submarine plateau were laid down. Then followed a period of volcanism during which masses of volcanic materials were erupted along the axis of elevation. Alternating epochs of upheaval and stable equilibrium ensued, during the last of which the reefs grew outwards and formed the terraces now so characteristic of the profiles of the islands. After the last upheaval the volcanic forces became again active. There is much of special interest in the account given by Mr. Andrews of the Lau Group. The blocks of limestone included in the volcanic agglomerates distinguish the Lau detrital rocks from those of Vanua Levu. There is no evidence that coral reefs existed during the early stages of the emergence of Vanua Levu to be obtained from the submarine formations found on the higher levels, 1,000 to 2,500 feet above the sea.

The period of emergence for this island may be divided into an earlier and into a later stage, the last corresponding to the age of emergence of the Lau Islands. The earlier stage, which may be termed the "Pre-Lau" stage, is represented by the deposits of the higher slopes of Vanua Levu, that is above 1,000 or 1,200 feet. This is really the critical epoch in the history of this group, and assuming that the movement of emergence has been fairly uniform over the archipelago we cannot but be astonished at the absence of all traces of ancient reefs in the earlier stage.

We may infer from the observations of Mr. Lister³ that the islands of the Tonga Group represent the Lau stage of the emergence. They are similar in height and in general geological

¹ See the paper before quoted on the coral reefs of Fiji.

² *Bull. Mus. Comp. Zool.* Harv. Coll. vol. 38. *Geolog. Ser.* vol. 5, no. 1, 1900. *On the Limestones and General Geology of the Fiji Islands*, by E. C. Andrews.

³ *Quart. Journ. Geolog. Soc.* vol. 47, p. 590, 1891. See also Mr. Harker's paper below quoted.

structure to the islands of Lau, that of Eua, for instance, which has an elevation of 1,100 feet, being formed of reef-limestones overlying volcanic tuffs. Dykes penetrate the tuffs but do not enter the incrusting calcareous strata. Mr. Harker,¹ after examining the collections of Mr. Lister, remarks that all the rocks excepting those from Falcon Island appear to be of submarine formation. The volcanic material, he adds, seems to have been almost exclusively of fragmental character. It would be rash, it is remarked, to refer all the rocks to a Recent age, and some of them may be found to go back far into Tertiary times.

My division of the long period occupied by the emergence of the Fiji Islands into two stages, the Lau stage corresponding to elevations of less than 1,000 or 1,200 feet, and the Pre-Lau stage which includes the earlier evidence of emergence found at heights exceeding these elevations and ranging up to 2,000 or 3,000 feet, may perhaps be applicable to other regions of emergence.

As bearing on the question of the isolation and antiquity of the Pacific Islands the following approximate results for the Hawaiian, Fijian, and Tongan floras may be here quoted.² These data are liable to correction; but they are near enough to the truth to be very suggestive. Of peculiar genera of flowering plants and ferns the Hawaiian Islands possess about 40, the Fiji Group about 16, and the Tongan Islands none. Of endemic species of flowering plants there are about 80 per cent. in Hawaii, about 50 per cent. in Fiji, and 3 or 4 per cent. in Tonga. Granting that there is much to be done yet in the investigation of these floras, it would be underrating the brilliant results of the labours of Hillebrand and Seemann to characterise their work as sampling. Let us suppose, however, that the floras of Hawaii, Fiji, and Tonga have been only sampled, the data above given would be still reliable. It is quite possible to obtain a botanical equivalent corresponding to the geological estimates of the relative ages of these islands; and taking the proportion of endemic plants as our guide, the Lau stage, as represented by the Tongan Islands, would have a value of 3 or 4, the Pre-Lau stage now exhibited in the earliest stage of emergence of Vanua Levu would have a value of 50, and the Hawaiian stage older than all would have a value of 80. These results are intended as suggestive and I hope to work

¹ *Geolog. Mag.* June, 1891.

² Seemann's *Flora Vitiensis*, Horne's *Year in Fiji*, Hillebrand's *Flora of the Hawaiian Islands*, Hemsley's "Flora of the Tonga Islands" in *Journal Linnean Society*, Botany, vol. 30.

out this subject in the second volume. They make the problem of the relative antiquity of these islands more mysterious than it even appeared before.

With regard to the vexed question of the light thrown on the past condition of these islands by the present state of their floras and faunas, it may be at once observed that my belief in the general principle that islands have always been islands has not been shaken by the results of the examination of the geological structure of Vanua Levu. In a correspondence in *Nature* about fifteen years ago it was suggested by me that this is the position we ought to take with regard to the stocking with plants of the islands of the Southern Ocean, such as Kerguelen; and I take the same standpoint for the islands of the Pacific. If the distribution of a particular group of plants or animals does not seem to accord with the present arrangement of the land, it is by far the safest plan, even after exhausting all likely modes of explanation, not to invoke the intervention of geographical changes. New possibilities of inter-communication, new ways of looking at old facts, and new discoveries of an unexpected nature come monthly before us in the progress of scientific research; and I scarcely think that our knowledge of any one group of organisms is ever sufficiently precise to justify a recourse to hypothetical alterations in the present relations of land and sea.

The hypothesis of a Pacific continent,¹ whether it takes a trans-oceanic form, as advocated by Von Ihering, Hutton, Baur and others, or whether it is represented by an island-continent isolated in mesozoic times, as suggested by Pilsbry, receives no support from the geological characters of Vanua Levu. Nor can I accept as regards Fiji Mr. Hedley's theory of the Melanesian Plateau. There is no evidence that the various islands of the Fiji Group were ever amalgamated and no indication of a geological nature that they were ever joined to the Solomon Group. The Fijis, as we see them, have had an independent history, and the process at work is not one of disruption but of amalgamation, lesser islands being united to larger islands during the prolonged period of emergence. Mr. Hedley, however, has some weighty data on his side more especially zoological; but even here it would be wise to suspend one's judgment. Though the great mass of botanical evidence is as respects Fiji opposed to such connections,

¹ See Hutton *Proc. Linn. Soc. N.S.W.* 1896, Baur, *Amer. Nat.* 1897, Pilsbry, *Proc. Nat. Sci. Philad.* 1900, Hedley, *Proc. Linn. Soc. N.S.W.* 1892, 1899, &c.

the distribution of *Dammara* may, however, be fairly claimed on their behalf.

The dilemma into which such discussions lead us is aptly stated by Dr. Pilsbry. If we do not accept the hypothesis of a Pacific continent, we have to explain the cessation of the means of transportal in later geological times, since this is implied in the isolation necessary for the development of peculiar characters in a fauna or a flora. This was the dilemma that presented itself to me in studying the origin of the Fijian plants. Assuming on geological grounds that the insular condition had been always maintained I had to explain the differentiation in the inland plants, or in other words to account for the failure of the means of transportal that once existed. Since this subject bears directly on the past condition of the Fiji Islands, I may be pardoned for referring to it here. It belongs properly to the second volume which it is proposed to devote to the dispersal and distribution of Pacific plants; but as I contest the pre-existence of a Pacific continent, it is fitting though not necessary that this difficulty should be faced at once.

If we in imagination combine in a typical island the characters of the flora presented by islands of different elevation in the Pacific we get a result of this kind in an island of the height of Hawaii, nearly 14,000 feet. The littoral plants of such an island are found all over the coasts of the tropical Pacific, and for the explanation of this fact we look mainly to the agency of the ocean-currents. The plants of the mountain summit, belonging to the temperate genera of *Geranium*, *Rubus*, *Ranunculus*, *Vaccinium*, &c., are represented at least generically on the tops of the lofty ranges of the Pacific coasts and in the interior of the continents; and we find the explanation of the wide diffusion of such plants in the agency of the migrant birds that at no distant time, if not actually in our own time, were regular visitors to these mountain regions. The plants of the marsh, of the stream, and of the pond, belong often to species that occur in similar stations over a great portion of the world, such as species of *Drosera*, *Ruppia*, *Potamogeton*, &c.; and here the agency of wild duck and other water-fowl may be observed in active operation.

But when in such an island we regard the intermediate region between the uplands and the coast, usually the forest-zone, we find an area of change not only for the plants but also for the birds. It is here that the new genera of plants have been developed that distinguish the floras of the Pacific groups each from the

others ; and here also the migrant bird, having from some cause changed its ways, has given rise to new varieties and to new species. It is with this loss of the migratory powers of the birds of the forest-zone that I connect many of the important differences between the forest-floras of the different groups of the Pacific. At one time, it would seem, birds were far more active agents in dispersing seeds and fruits over these archipelagoes than they are at present ; but it is not held that this is concerned with the extermination and extinction of the birds of these islands in the present day. The change dates far back and is far-reaching in its effects. It is assumed in this argument that the alpine plant and the plant of the pond and of the sea-shore preserve their characters by reason of the means of free dispersal that they still enjoy ; and it is inferred that the plant of the forest-zone has varied more because opportunities of transportal of its kind no longer are afforded. Many a line of ancient migration is now broken.

It is suggested that in the past when birds were more generalised in type they were much more migratory in habits and that limitation of range has been associated with specialisation. The plants dispersed by the birds have undergone a parallel series of changes. At first widely distributed, as in the more generalised types of birds, they became localised in proportion as the birds to which they owed their means of dispersal lost their migratory ways ; and both plant and bird began to vary. There is, I am convinced, a profound connection between birds and plants, of which we now perceive only the last of a long series of changes. This subject will be dealt with at length in the volume on plant-dispersal ; and it is only referred to here to illustrate my contention that we have yet much to learn before it would be safe to look to hypothetical changes of sea and land to explain difficulties in distribution.

APPENDIX

Note on the Stone-Axes.—Two of these polished stone-axes from a collection made in Vanua Levu were selected for sections. One is light-green and smooth. The other has a very different appearance, being blackish and rather rough, its smooth surface having been apparently lost by lying in a stream-course or in wet ground for a long period. Both, however, are made of the same type of basaltic rock, the specific gravity in one case being 2·93, in the other 2·97. It is an aphanitic basalt with scanty olivine containing little or no residual glass and referred to genus 40 of the olivine-basalts. It is by no means a common type of basalt in Vanua Levu, and I cannot refer it to any particular locality on account of the peculiarities it presents when contrasted with rocks of the same genus. The olivine is very scanty and small, and in one of the specimens is represented only by pseudomorphs. The felspar-lathes vary usually from ·05 to ·2 mm. in length, and the augite granules which are very abundant are ·01 or ·02 mm. in diameter. There is an occasional small phenocryst of augite. The rock shows little or no alteration and cannot be characterised as a greenstone. The greenish hue of one axe is due to weathering; but its extension into the internal black portion of the tool is not appreciable.

Note on the ascent of the tide up the Ndreketi River.—On July 20th and 21st, 1899, by observing the surface density it was ascertained that at high-water the sea-water reached Navundi a mile or two below Mbatiri. At low-tide it reached about half-way between Kanathangi and Navundi. The moon was in her quarters.

Note on the "talasinga" districts.—This subject will be discussed in the second volume.

INDEX

NOTE.—It has been deemed best to follow the example of the Admiralty surveys in the spelling of native names. In this book, therefore—

Mb = the Fijian B
Th = „ „ C
ND = „ „ D
NG = „ „ G and Q

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¹ The term “basalt” is here used in a general sense to include olivine-basalts, basaltic andesites, and other basic types of the augite-andesites and hypersthene-augite andesites.

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¹ The usual signification of "koro" as a prefix or part of names of hills and mountains is a "prominence" or "projection." It is a mistake on my part to assume that in such cases it is as a rule equivalent to a town or village.

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